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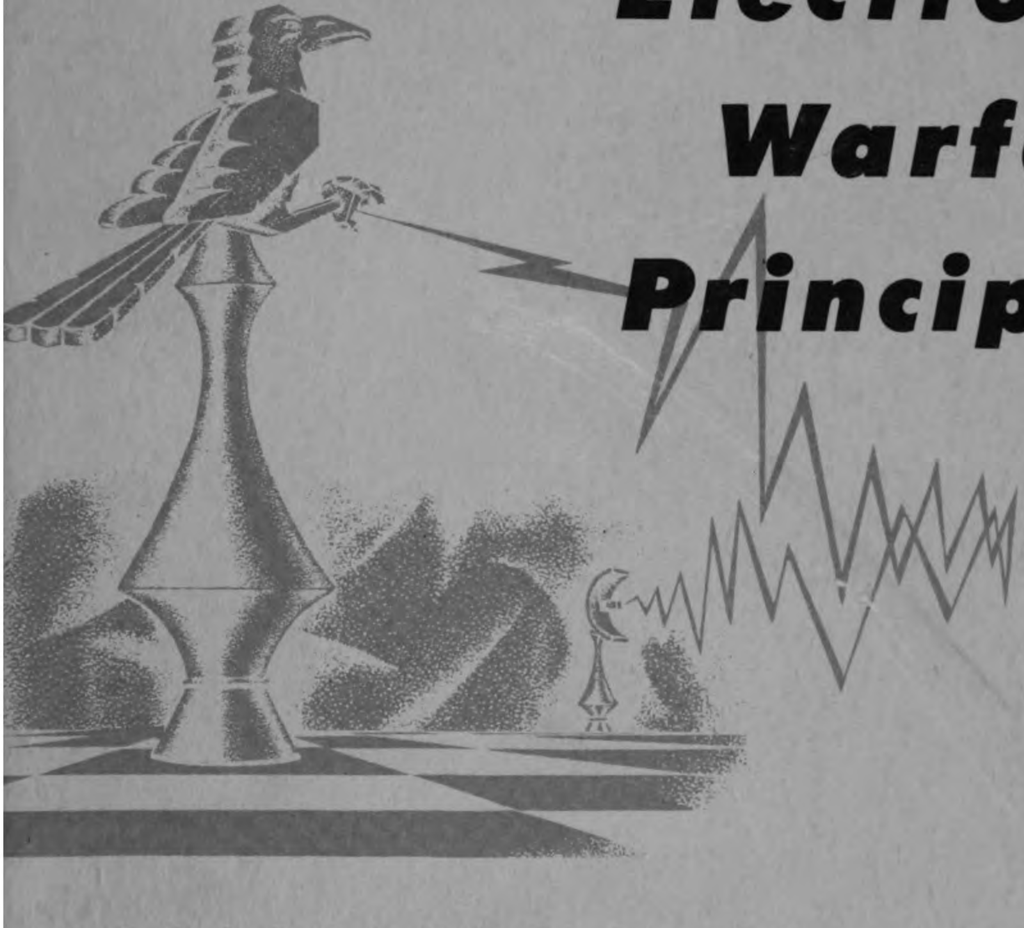
Electronic Warfare Principles



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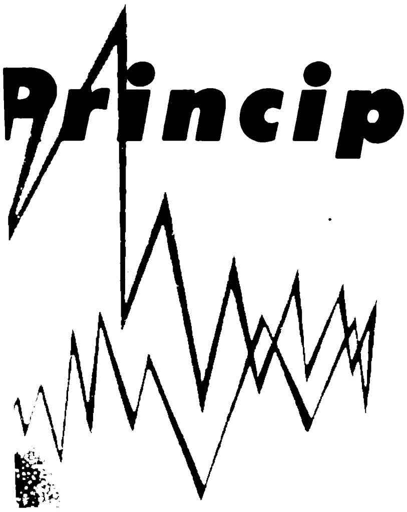
Electronic Warfare Principles



DEPARTMENT OF THE AIR FORCE

AIR FORCE MANUAL
NUMBER 51-3

DEPARTMENT OF THE AIR FORCE
WASHINGTON 25, D.C.
1 November 1962

Flying Training

ELECTRONIC WARFARE PRINCIPLES

This manual contains general information on a variety of subjects of prime interest to the electronics warfare (EW) officer, including instruction in EW theory and in the duties of an EW officer. It is designed primarily for the instruction and guidance of the EW officer, but it provides a valuable source of basic EW information for all personnel requiring such knowledge.

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Forward recommendations for improving this manual to Headquarters Air Training Command, Randolph Air Force Base, Texas.

CHAPTER 1

Introduction to Electronic Warfare

Electronic countermeasures during World War II was aptly named "The Battle of the Beams." As this name implies, electronic warfare is often the combating of one electromagnetic wave with another. This type of warfare is based on the theory that what one electromagnetic wave can do may be undone by another.

Sir Winston Churchill referred to earlier electronic warfare as "The Battle of the Wizards." He left no doubt that it was the skill and knowledge of the scientist that played an important part in winning World War II. The behavior of electromagnetic energy had to be understood before electromagnetic waves became weapons of offense and defense.

The use of electronic equipment in warfare has expanded to include virtually all areas of combat. Extensive radar networks provide advance warning of an enemy attack, and weapons guidance systems aid in defense. These electronic networks are capable of guiding interceptor aircraft to within very close range of threatening bombers. Electronic defense becomes further complicated when an attacking aircraft utilizes maneuvers and electronic countermeasures to confuse or falsify information obtained by electronic equipment.

An air crew penetrating an enemy defense must be able to keep the enemy's defensive electronic equipment out of action or confused. This is accomplished by the use of special transmitters and reflective devices designed to take advantage of those characteristics of electronic equipment most susceptible to countermeasures.

EARLY HISTORY OF ELECTRONIC WARFARE

Electronic countermeasures first appeared during the early part of World War II. The rapid development and expansion of radars as detection and control devices created an immediate countermeasures requirement. Since radar was the primary objective of countermeasures, the field was known as RCM or radar countermeasures.

As radar progressed, radar countermeasures personnel tried to keep pace and constantly tried to foresee and prepare for new radar developments. It was essential that there be as little time lag as possible between the use of a new weapon and the use of its countermeasures.

The principles that were used to counter World War II radars are still effective today. It is important to understand the requirements that led to the development of these basic countermeasures techniques.

British Activity

The threat of war greatly accelerated Great Britain's development of radar. In 1935, The Air Ministry's Committee for the Scientific Survey of Air Defense received a carefully worked out plan from the Scottish physicist, Sir Robert Watson-Watt, who suggested a pulse method for the detection of aircraft. The suggestion was adopted, and in December the Air Ministry decided to establish a chain of five radio-locating, early-warning stations about 25 miles apart to protect the Thames

Estuary. These stations operated on a frequency of about 26 mc. By March of 1938, all these "chain home" stations were complete and in operation. This was the first operational system installed anywhere in the world. Later, fifteen additional stations were added to complete the coverage of the east and southeast coasts of England.

When Prime Minister Neville Chamberlain flew to Munich in September 1938, these stations were put on a 24-hour watch for the first time. After a short time this was stopped. However, with the German occupation of Prague in March 1939, around-the-clock operation was resumed.

British development, at the same time, centered on airborne radar equipment. Two types were deemed necessary. One type, called ASV (air-to-surface vessel), was used for the detection of naval vessels by patrol aircraft. The other type allowed night fighters to intercept and home on enemy aircraft. It was called AI, for aircraft interception. The ASV set was demonstrated during fleet maneuvers in September 1938. In August of the following year, the AI set was demonstrated to the RAF. Four of these AI sets were ready on the day that war broke out; 30 sets were completed and installed by the end of that fateful month, September 1939.

These various radar installations have had a profound effect on world history. During the Battle of Britain in 1940, radar control made it possible for 700 British fighter aircraft to defeat a force of some 2,000 German bombers.

The development of airborne equipment and the completion of the Chain Home radar net was matched by other developments as well. During this period, the Plan Position Indicator was developed. This indicator provided a map-like presentation of the area swept by the radar. It was used first for the control of night fighters, and later for antisubmarine warfare and blind bombing.

American Activity

In the United States, the Signal Corps designers first turned their efforts toward a pulse system of detection in 1934. The first design was completed in 1936 and successfully demonstrated in 1937. The United States Naval Research Laboratory also began work on a pulsed detecting system in 1934. A Navy set designed for field service was given tests at sea during battle maneuvers early in 1939 on the USS New York. In 1941 the first wholly automatic tracking of a target aircraft was accomplished.

While the Navy was installing search and fire control radar on ships of the fleet, the Army was equipping antiaircraft batteries with the SCR-268 and sending out Signal Aircraft Warning Battalions with the SCR-270, a set which was later used to detect the Japanese bombers approaching Pearl Harbor.

American-British Collaboration

Before the pooling of British and American interests in 1941, British development of radar was well in advance of that in any other country. To produce sharp radar beams with antennas small enough to be carried in airplanes, microwaves (waves shorter than one meter) had to be used. Shorter wavelengths produce narrower scanning beams from a given antenna. A narrow beam provided the advantages of greater range of detection for a given amount of power, greater accuracy in determining angular bearing, less interference from ground return, and, most important of all, better target resolution.

In the United States, the National Defense Research Committee (NDRC) set up a section in July 1940 to investigate the possibility of using microwaves in aircraft detection. This committee became discouraged by the lack of means for generating enough power for long-range operation at the high frequencies involved. The British, meanwhile, had solved this problem by developing a resonant cavity oscillator. The magnetron, as this device was called, was a sensational improvement on a Japanese modification of a crossed field tube which an American company had developed and found "impractical" in 1921. The new magnetron was practical, but the British were not able to mass produce it.

In September 1940, as a result of an agreement between the American and British governments to exchange technical information of a military nature, a British mission arrived in Washington. They brought detailed manufacturing information as well as samples of the cavity magnetron. The mission suggested that the United States undertake two specific projects: the development of a microwave AI system, and a microwave position finder for AAFC (antiaircraft fire control).

To carry out these suggestions, the NDRC set up a development laboratory at the Massachusetts Institute of Technology, staffed by physicists from a number of universities and technical experts from the radio industry.

In December 1941 the United States went to war. The Navy, foreseeing the need for radar equipment, made funds available for the erection of a factory to produce microwave tubes. Facilities were planned for a maximum production of 100 magnetrons per day. Immediately the demand for the tubes increased from the hundreds to the tens of thousands. Since sufficient machine tool capacity was not available to meet this need, the magnetron was expected to become the bottleneck in radar production.

However, the United States soon developed a mass production system known as the lamination method which eliminated precision machine work. By this method, the anode configuration was stamped out of copper sheets and the punchings were stacked on precision jigs and then brazed together. All manufacturing was converted to this technique and magnetrons were produced on a series of production lines. This development made extensive use of microwaves a practical possibility.

As the war progressed, various tactical requirements dictated the need for new types of radar. Sets were required to direct the guns of the big battlewagons, to search the skies for planes, to direct the searchlights, to track fast-flying buzz bombs, to act as beacons, to direct precision bombing from the skies, and to assist in the landing of aircraft.

During the war years, the United States invested more than $200 million in research and development of radar, and over $2.7 billion in the manufacture of service equipment.

During this period, various news reports implied that radar was the Allies' number one secret weapon, that the conflict was essentially a radar war, and that radar would win the war for the Allies. These reports were optimistic. Like every weapon, radar can be countered by other weapons, and the radar duel between the combatants was settled not so much by radar supremacy as by superior countermeasures.

British Electronic Countermeasures

Electronic countermeasures were developed almost as rapidly as radar. In September 1939, the Germans utilized a zeppelin to perform extensive electronic reconnaissance in the North Sea area. Using sensitive receivers, they attempted to detect and evaluate British experimental transmissions in the high-frequency range. These zeppelin flights were actually plotted by the British with their radar. Unfortunately for the Germans, however, their intercept receiver which covered the British-used frequencies was inoperative. The German operator, who was afraid to admit that his equipment had failed, simply reported that no signals were present.

As a result of this report, the Germans underestimated the British capabilities. Their planning was based on a short offensive war, so they standardized their own radar production on a few types and virtually ceased all development and research. Many of their electronics engineers were drafted into other types of work.

In England, however, ECM was recognized as a vital phase of World War II military operations. One of the first leaders in that war to so recognize it was Sir Winston Churchill. In his war memoirs he wrote that if British science had not proven superior to German in the development and application of electronic countermeasures, the British might well have been defeated and destroyed.

United States ECM

Before our entry into the war, some attention had been given to electronic countermeasures by the Naval Research Laboratory and the Radiation Laboratory at Massachusetts Institute of Technology. The U.S. Forces had also been watching the British program and were aware of the need for intensive research in this new field. In December 1941, they formally requested the National Defense Research Committee to undertake a separate project in radar countermeasures. This led to the founding, early in 1942, of the Radio Research Laboratory at Harvard University.

At this time, little or nothing was known in the United States about the specific details concerning enemy radar equipment. Information on countermeasures which the British had developed to neutralize radars was also meager, so it was mandatory that close liaison be established with British circles which already had operational experience with radio and radar countermeasures. In the spring of 1942, a small number of research personnel from the United States went to England to work with RAF radiation countermeasures personnel.

JAMMING REQUIREMENTS. Through electronic reconnaissance and the examination of captured enemy equipment, interested Allied personnel were able to gain an idea of the magnitude of Germany's preparations for a radar war. Continued investigation revealed that the Germans were equipped with five major types of radar operating at frequencies from 100 to 600 mc. These were used for early warning, coast watching, aircraft interception, antiaircraft fire control, and ground control of interceptors.

The immediate task of the Radio Research Laboratory was to devise equipment capable of reducing the effectiveness of all known German radar systems.

Jamming transmitters which met two basic requirements were needed. Each transmitter needed a wide tuning range to increase versatility and to decrease the numbr of transmitters required. It also needed sufficient modulated power output to provide a continuous jamming signal, while maintaining the important properties of light weight and compactness. Weight and space requirements were critical, since most of the jamming equipment was intended for airborne installation.

The determination of the type of modulation to be employed presented many problems. After many experiments, wide-band random noise was selected as the modulating signal. Because of its complex frequency characteristics, it was not susceptible to ordinary antijamming (AJ) techniques in use at that time.

Development of transmitters operating at about 200 mc proved to be a formidable problem, since in 1942 there were very few vacuum tubes capable of operating at the higher frequencies. The only ones which showed promise of practical operation, at the microwave frequencies, were the recently developed doorknob tubes.

From these tubes came the oscillator of the "Carpet I" jamming transmitter which tuned as high as 720 mc. Following "Carpet I" and a similar device called "Rug" came "Carpet III"—a transmitter designed to jam German flak-control radar operating from 460 to 585 mc. This piece of equipment found wide usage in the 8th and 15th U.S. Air Forces during the latter part of the war against Germany.

TRAINING. ECM was a very hush-hush business in the latter days of 1942. Regardless of classification, however, a school was required to train Air Force officers in the field of countermeasures. In January 1943, an ECM school was organized at Boca Raton, Florida, then the hub of electronic countermeasures in the Air Force.

During World War II almost 600 officers were graduated from this school. Of those graduated, less than 100 participated in the reconnaissance program associated with ECM. Many of the others were assigned to bomb organizations which set up the jammers that countered the enemy's radar.

Two members of the first graduating class took part in the first use of U.S. designed countermeasures equipment against the enemy. They were assigned to a B–24 "ferret" aircraft and sent to the Alaskan theater to scout suspected Japanese radar on the island of Kiska. This plane, the first of a long line of such ferrets, was successful in locating two potentially dangerous Japanese radars on that island.

This first U.S. ferret mission proved the feasibility of electronic reconnaissance and pointed out the need for more and better equipment.

The Invasion of Sicily

In April 1943, the second U.S. ferret was sent to North Africa at the request of the theater commanders there. To prepare for the invasion of Sicily, which was planned for July of that year, the Allies wanted to knock out the radar stations along the coasts of Sicily and Sardinia.

Radar intelligence was successful in pinpointing the locations of these potentially dangerous German radar sets. Once the locations had been determined, Allied fighter-bombers were sent in to bomb and strafe them.

The landings themselves were protected by trained Navy teams using jamming transmitters. The jammers took the German coast-watching radars out of action and prevented the accurate direction of gunfire against our assault craft.

The 8th Air Force

During the latter stages of the war in Europe, the 8th Air Force sent several planes equipped with intercept receivers on nearly every bombing mission over Germany. The operators kept a record of all German radar signals intercepted. This advance information on the frequency distribution of German radar proved to be of vital importance in the successful large-scale radar jamming activities that were begun by the 8th Air Force in the fall of 1944.

As early as October 1944, two bomb groups in the 8th Air Force had been equipped with carpet jamming transmitters which were flown on each mission. This sudden development took the Germans completely by surprise and resulted in reducing bomber losses due to flak in these two groups to about half that experienced by other groups. This success led to the equipping of the entire 8th Air Force with electronic jammers, a task involving the field installation of over 6,000 pieces of equipment.

After the war, German officers admitted that under unfavorable conditions of jamming, 3,000 rounds of heavy ack-ack were fired for every bomber shot down, as against an average of 800 rounds or less required per kill under conditions of no-jamming. In many cases this waste of shells was so alarming that the flak batteries involved were ordered to cease operations.

Electronic jamming was not the only active countermeasure against the German radar. The RAF introduced "window" during their night bombing raids on Hamburg. Ironically, the Germans also had considered the use of reflective material, but had not used it, since they realized that their own radar systems were more vulnerable to this countermeasure than were the British. After many experiments, the U.S. Forces determined that they achieved best bombing results when electronic jamming was supplemented by chaff.

Throughout the war, the 8th Air Force was the biggest user of electronic countermeasure equipment. However, the smaller 15th Air Force in Italy also carried out an intense program.

In addition, radar countermeasures played an important part in many of the large-scale naval landing operations, particularly in the invasion of France. Hundreds of jamming transmitters were carried in this operation to jam the German coast-watching radars and those radars used to control the fire of coastal defense guns. Deception was used also. A fleet of small ships carrying jamming transmitters was sent toward Calais while, overhead, circling aircraft dropped great quantities of chaff.

This maneuver helped convince the German High Command that the invasion would occur north of the Normandy beaches, and this German error in judgment contributed to the success of the invasion. The scope of the ECM activities carried on by the Air Force on D-Day is depicted in figure 1–1.

Pacific Theater

In the Pacific theater electronic countermeasures were not used as extensively as in the European theater. The reason was that Japanese radar was generally inferior and less abundant than German radar.

Passive countermeasures were used by each of the numbered air forces in the Pacific. The 20th Air Force used both jammers and window in their raids on the Japanese home islands. In addition, an ECM officer with intercept receivers accompanied each group to monitor the frequency spectrum used by the Japanese.

Late in the war, the 20th Air Force utilized "porcupines." These were jammer-equipped aircraft which carried a huge fuel load instead of bombs. They accompanied the first wave of bombers to jam out the Japanese fire-control radar, and they continued circling in the target area until the last bomber had dropped its bombs.

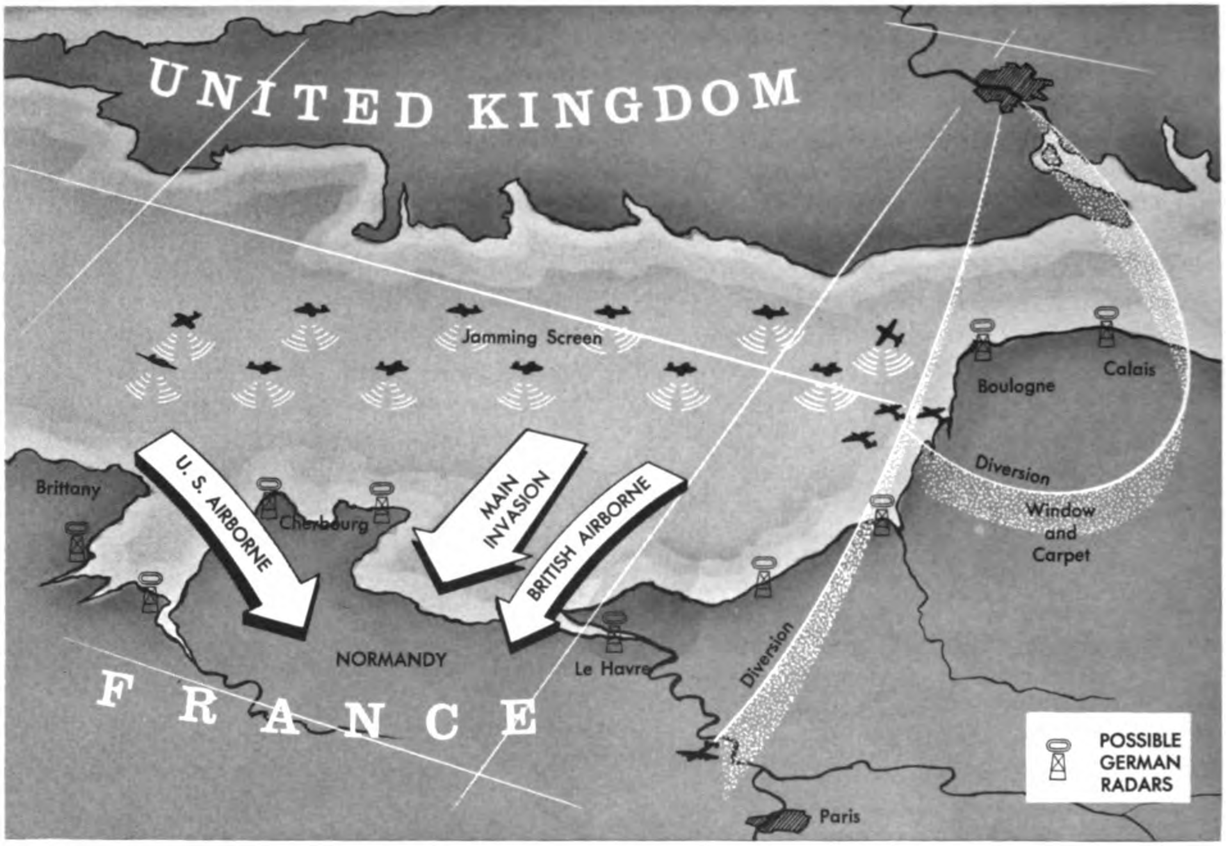


Figure 1–1. *ECM Operations on D-Day*

Summary

The value of the ECM program during World War II was tremendous. Countless aircraft, lives, and equipments were saved from damage or destruction through successful countermeasures.

At the end of World War II, permanent peace seemed assured, and the Armed Forces were rapidly demobilized. Since they were short of both men and financial resources, the Armed Forces declared an "electronics-countermeasures holiday," and for more than two years very little research was done in the field of electronic countermeasures.

An effective research and development program was reestablished in 1948.

With the advent of new weapons, every commander must place more and more reliance on the successful operation of electronic equipment. The field of countermeasures is still wide open, and has become one of the most important in the defensive and offensive strategy of this nation. The significant lessons learned in the use of ECM during World War II illustrate the danger of becoming satisfied with current weapons systems.

MILITARY USES OF ELECTROMAGNETIC ENERGY

The importance of electronics to a modern military force is immeasurable. Expansive operations are possible as a result of the development of electronics in its many facets. In early history, the scale of operations was limited by the ability of the commander to communicate with his troops. Today, through electronic systems, the span of control may be extended into outer space.

Communications

Electromagnetic waves have been used longer for communications than for any other purpose in military operations. Not only are communication techniques improving in range, they are developing in other areas as well. New systems are being made to improve the reliability and security of these systems.

The Air Force has communication requirements other than world-wide coverage. Tactical and strategical operations require communication systems tailored to their assigned missions. Continental defense operations require other techniques. The following discussion is a review of airborne communications.

LIAISON COMMUNICATION SYSTEMS. Liaison communications systems consist of long-range equipment. Traffic handled by these systems includes weather information, position reports, instructions, and strike reports. The range of this equipment varies from fifty to several hundred miles. In order to get this long-range, single-sideband high-powered HF equipment is used.

COMMAND COMMUNICATIONS. Command communications are used for exchanges of information between aircraft and ground installations. This equipment is characterized by line-of-sight transmission and reception, low-power, lightweight, and simple operation; and it usually operates on a limited portion of the frequency spectrum. Within the United States Air Force it operates in the VHF or UHF bands. In interceptor aircraft, command sets are used to receive vectoring information from controllers.

GROUND CONTROLLED INTERCEPTION COMMUNICATIONS. Ground controlled interception (GCI) communications are of special importance to the electronic warfare officer. Two methods are used: voice communication and data link transmission. GCI operations direct interceptor aircraft or missiles against strike aircraft. Countermeasures against this type of communication is an effective defense measure for the attacking aircraft.

GCI operations are limited in range by the observing radar; thus, short range communications are satisfactory. UHF and VHF bands are often used in GCI operations, since their limited range poses no handicap, and components designed for these frequencies are relatively small and light. Some foreign countries also use the HF band for this purpose.

Signals directing interceptor aircraft are intermittent and concise. They may or may not be coded. Most of the traffic is from the ground controller to the interceptor. The interceptor need only transmit short acknowledgments. As the interceptor enters the final phases of the intercept, traffic increases until contact is made.

Radar

Early warning detection during the first World War was by means of sound waves. This method became outmoded as the speed of aircraft increased. The answer to the problem of detecting high-speed attacking aircraft in time to send interceptor aircraft aloft was found in the use of electromagnetic waves.

Early studies of electromagnetic energy proved that these waves could be bent and reflected just as light waves are; however, electromagnetic waves were not used for detection of ships and aircraft until just before World War II.

The development of radar depends on these principles: energy radiated from an RF transmitter may be focused into a narrow beam; energy may be sent out in short high-power bursts, at approximately the speed of light; bursts of energy striking a target return to the transmitting site with sufficient strength to energize a sensitive receiver; and reflected pulses of energy can be displayed in a manner to indicate the direction and distance of the target from the transmitting site.

Today all the major nations have overlapping beams of electromagnetic energy about their boundaries, forming a continuous warning screen. These constantly scanning beams pierce far into the skies and extend out several hundred miles. This electromagnetic curtain is generally higher than the maximum altitude of conventional combat aircraft. These rings of detection equipment are needed to give sufficient warning time for defensive or retaliatory action.

EW RADAR. Radar equipment for warning purposes is classed as early warning (EW) equipment. To do the best job of early warning, it must have the longest range possible. This requires extremely high-powered equipment with large, heavy antenna assemblies. It may or may not be mobile and can be operated in the VHF, UHF, or SHF bands. There is little probability that an aircraft could penetrate an electronic net composed of modern EW radars without being detected.

IDENTIFICATION, FRIEND OR FOE. After the detection and location of an approaching object by radar, the target may be interrogated and identified by a special coded electromagnetic wave. This coded signal is designed to trigger equipment carried by all friendly aircraft and ships. When this equipment is triggered by the interrogating signal, it, in turn, sends back an identifying coded signal. Techniques for identifying unknown targets are known as identification friend or foe (IFF) or selective identification features (SIF).

IFF/SIF equipment does not require as much power as radar, since it does not depend on a reflected signal. IFF/SIF equipment includes a transmitter in the aircraft which returns the signal, whereas radar must send out sufficient power to get an echo from the target. IFF/SIF equipment is usually operated in the UHF band, but can be operated in the VHF or SHF bands.

GROUND CONTROLLED INTERCEPTION (GCI). If an approaching aircraft cannot be identified as friendly, it is assumed to be "hostile" or "unknown" in peacetime and appropriate defensive measures are taken. This involves tracking the target and guiding intercepting aircraft or missiles to it so that a quick and efficient intercept may be accomplished. The controlled intercept technique is often referred to as ground controlled interception. Radar is employed in this operation to pinpoint the position of the target and the interceptor so that the interceptor may be guided on an accurate approach path.

PRECISION RADAR. Highly accurate radar sets have been designed with automatic and manual-aided tracking capabilities that can determine the position of the target within a few yards. The extremely narrow pulses they produce enable them to determine range very accurately. Elevation and azimuth can be determined accurately with these radars by use of narrow beams and special scanning techniques.

Precision radar finds many uses in missile warfare. Extremely accurate tracking is required in many launching techniques. The control of defensive ground-to-air missiles is aided by accurate tracking information from precision radar sites, whereby the tracking coordinates of the target are fed into a missile guidance system computer. The computer continuously calculates the intercept path and predicts the missile path to the target.

Infrared

Radar systems have been supplemented by infrared systems. Infrared systems are lighter, more compact, and provide better angular resolution, yet lack the range accuracy of radar systems.

Navigation

Numerous fixed aids to navigation have been developed to assist in point-to-point navigation. Among those requiring ground and complementary air/surface equipment are low frequency ranges, VHF marker beacons, VHF ranges, TACAN, LORAN, and SHORAN. Self-contained airborne systems are probably best illustrated by the modern aircraft precision navigation/bombardment radar systems. All of these systems are vulnerable to ECM and should not be relied upon in a hostile electronic environment.

Missile Guidance

Defensive missile guidance systems are predominately electronic and are susceptible to jamming and deception. Radio command guidance is readily adapted to surface-to-air missiles. The radio command guidance system uses one ground radar to track the invading aircraft, and another to track the intercept missile. This tracking information is fed to a computer where guidance is generated to steer the missile to the target.

Another form of command guidance is called "beam-riding." A narrow radar beam is trained on the intercepted target and the missile is computer-controlled to ride the beam to the target.

The above guidance systems have one weakness in common—guidance becomes more susceptible to error as the missile moves away from the controlling radars and nears the target. This weakness is avoided by using ground guidance only to the target area and then employing a self-contained seeking system for final control. Passive seekers pick up emanations from a target and steer toward it. Active seekers transmit pulses of radio energy and steer toward the reflecting object. In a device using a semiactive homer, a transmitter illuminates the target with radio waves from the ground. These waves, reflected from the target, guide the missile to the kill.

Some air-launched missiles are directed against cities many miles from the mother plane. These missiles may contain equipment that will home on the infrared energy given off by a city or industrial area. In another type of guidance system, television equipment in the missile scans the ground ahead and transmits a picture by microwave beam to the mother airplane. This TV information is used to guide the missile to the target.

Long-range surface-to-surface missiles may steer toward a selected point in a pattern of radio waves marked out in space. Beyond the range of line-of-sight radio, the guidance problem becomes more difficult. Here the missile must steer by some reference, such as the earth's magnetic field. In the automatic astronavigation system, photosensitive tubes note the position of certain stars through stabilized telescopes. This celestial information, when processed by an electronic computer, can locate the missile relative to a point on the surface of the earth and provide any necessary course corrections to lead it to its target.

Some ballistic and orbiting missiles are put into a prescribed trajectory through combinations of inertial and command guidance techniques. The trajectory that the missile is to fly is computed electronically and programmed into the guidance system. After blast-off, the missile trajectory is tracked by radar and compared to the programmed flight path. Corrections are transmitted to the guidance controls through a command system.

Electronic Countermeasures

The importance of ECM in modern warfare must never be underestimated. Without ECM, the present day electronically controlled defensive systems could inflict unacceptable attrition on attacking forces. And likewise, without proper ECCM fixes, electronic defense systems cannot function effectively in a hostile ECM environment.

The future role of ECM was well expressed by Major General Gordon P. Saville in 1952 when he summed up defensive and offensive fire control in air action as follows:

"Let's speak for a moment about the relationship that exists in strategic warfare between the air offense on the one hand, and air defense on the other. That is, the relative capability of the air offense as opposed to the air defense.

"Right now, it is probable that the air offense can accomplish its mission in spite of the air defense. This is due partly to the state of the art, and partly to what was done with the state of the art. Now let's see what's going to happen.

"I think that it's foreseeable that the air defense capabilities are going to overtake the air offense capabilities. This results from air-to-air missiles, ground-to-air missiles, supersonic rockets, barrage fire, better fighter application, and things of that nature. Hence, we turn the air defense wheel a couple of notches forward, thereby changing the relative position of air offense and the air defense.

"What are we going to do to the air offense to get it to catch up those two notches that air defense has advanced? The answer is that other means of negating the systems capability of the electronic control system of the air defense must be found.

"This means electronic countermeasures systems are going to be established in the near future as a matter of number one urgency and number one priority, in order for us to have a means of bringing these two (air defense and air offense) into balance. Always, in everything we do, electronic systems will form an ever-increasing part."

Today the air defense wheel has advanced as General Saville predicted. An example is the challenge that air power faces in the air-to-air homing missile. Such a missile is within the electronic arsenals of today.

ECM is divided into two phases, passive and active.

THE PASSIVE PHASE. The passive phase is primarily one of electronic reconnaissance, the collection of enemy radio and radar intelligence. During this phase, every effort is directed toward the collection, evaluation, and dissemination of intelligence concerning the potential enemy's electronic systems.

Before the enemy's electronic gear can be rendered ineffective, technical details of that equipment must be determined and evaluated. Thus, search or reconnaissance operations must precede jamming, deception, or antijamming operations.

With proper equipment, search operations obtain all possible information about the enemy's electronic equipment. Proper analysis of this data provides information on the use of radar, the approximate coverage in range and altitude, the accuracy, etc. This intelligence is then used in preparing jamming or bombing penetration mission plans, and in the development of new ECM equipment so that enemy electronic weapons may be countered in an effective manner.

THE ACTIVE PHASE. The active phase of electronic countermeasures makes use of the intelligence gained in the passive phase. The primary objective of this phase is to deny the enemy valid intelligence which is normally available from his electronic systems. This may be accomplished in several ways: jamming, deception, evasion, and destruction.

A strike mission supported by ECM may be planned to employ any of these techniques or a combination of all of them.

Jamming. Jamming is the deliberate creation of spurious signals designed to impair the enemy's radio, radar, or other electronic reception or control equipment. This category is divided into two subdivisions, electronic and mechanical.

There are three general types of electronic jamming: *spot*, *barrage*, and *sweep*. The three names are almost self-explanatory. Spot jamming means the jamming of *a* signal; barrage jamming is the simultaneous jamming of numerous frequencies contained in a wide band; and sweep jamming is continuously moving the jamming energy over a selected frequency band.

Spot jamming offers the advantage of putting maximum jamming power on a single enemy signal, while its disadvantage is that an operator must select which frequency is to be jammed, leaving others in the same frequency band untouched.

On the other hand, barrage jamming covers a wide band of frequencies, does not require a skilled operator, but has low power per megacycle.

Sweep jamming attempts to use a spot-jamming type signal to cover many signals by moving it continuously throughout a selected frequency band. However, sweeping too wide a bandwidth or at a nonoptimum sweep speed produces too few hits and insufficient dwell time.

Mechanical jamming is accomplished by the use of reflective devices reradiating the signals from enemy radars. Some literature has listed them as deceptive devices. *Chaff* or *window* consists of strips of metal foil cut to approximately one-half wavelength of the radar frequency to be jammed. As such, it is specialized, and different lengths must be used for different frequencies. *Rope* is the term given long metal streamers of foil employed against low frequency radars. Rope is referred to as *untuned*, because it is not cut to resonate at a specific frequency.

Deception. Webster defines this as causing to mislead, delude, or divert. Examined from an EW viewpoint, this definition is quite valid. To accomplish this, use is made of reflective devices and repeaters. Chaff and rope are used in this technique to hide real targets and create false targets.

Repeating or spoofing is an electronic means of making one target appear as several when viewed on the enemy radar scope. To accomplish this, a transceiver is employed which, when triggered by a radar signal, will transmit a series of short pulses on the received frequency. When these pulses are received by the ground radar station, they appear as returns from a number of aircraft.

Evasion. Evasion makes use of radar range and altitude coverage information obtained through reconnaissance. When this data is available, a penetration route may be selected which will bring the force under minimum surveillance. The technique of evasion also takes advantage of terrain features when planning a strike. For example, the striking force could be routed from behind a mountain where it would be screened from the radar until the last possible moment. In other cases, the aircraft is flown at extremely low altitudes to escape radar detection and tracking.

Destruction. Little need be said in the way of explanation of this technique. A well placed bomb or rocket can deprive the enemy of his electronic equipment, and possibly his electronic technicians as well.

Communications. Up to this point, only radar jamming has been discussed. Another field which must not be overlooked, but against which EW can be employed profitably, is communications. Both point-to-point and air-to-ground links are subject to attack, either from ground-based jamming or by airborne equipment. If ground-based jammers are to be used, consideration must be given to the frequency, power, and location of the victim station.

Noting that radio frequency energy is dissipated inversely with the square of the distance, it can be seen that a jamming source of low power output located near the receiving station can completely block out a signal from a more powerful transmitter located further away, providing the jammer can be located in the radar beam. The Soviets successfully use this application in jamming the Voice of America broadcasts.

Earlier it was stated that no feasible way existed to communicate rapidly and efficiently from ground-to-air except by electronic means. In GCI work, the ground-control positions the interceptor aircraft to commence a firing run. With the speed of today's bomber and interceptor aircraft, this positioning becomes of utmost importance. If the ground-to-air communication is jammed, the pilot may never arrive at a point where his airborne radar equipment can take over to complete the firing run.

ECCM

Electronic countercountermeasures (ECCM) are defined as the tactics and techniques used by electronic systems to reduce the effectiveness of ECM. A law of physics states that for every action there is an equal and opposite reaction; or, restated, for every ECM there is an ECCM.

ECCM includes circuits and techniques calculated to negate ECM. However, the primary emphasis for good ECCM must begin with well-qualified personnel. To be well qualified, electronic system personnel must be given every opportunity to train in an ECM environment.

DUTIES OF THE ELECTRONIC WARFARE OFFICER

The overall responsibility of the electronic warfare officer (EW officer) is to provide the planning, training, and operational knowledge required to support the unit EW program. This responsibility requires that the EW officer have a comprehensive job knowledge within his specialty; an understanding of the principles and doctrines of air (and to some degree, ground) warfare; plus a familiarity with associated agencies within the Air Force organizational structure, affected military services, and ancillary civilian companies and representatives.

While the EW officer AFSC (1571/75, defined in the job description at the end of this chapter) is in the combat and operations career field, assignment and utilization of EW officers are not limited to duties within this field. EW officers are required in intelligence, communications and electronics, armament, and materiel career fields. Within the combat and operations field, the duties of the EW officer begin with duties at squadron level and progress to staff duties at all levels of command.

Presented here in a realistic light are the duties and duty situations that will confront an EW officer. To attempt to define in specific terms electronic warfare personnel responsibilities at all levels and in all commands would be, to a large degree, purposeless and perhaps misleading.

The electronic warfare career field is one that tends to defy molding into any set pattern. Basically, it is a field that is *technical*, *classified*, and *dynamic*. These career field characteristics have, in the past, aided in isolating EW personnel and creating an aura of mystery and secrecy about the ECM business, all to the detriment of the program. To remain clothed in this mantle of mysticism will only continue past shortcomings. By achieving and exhibiting professional capabilities, the EW officer can make a tangible contribution toward attaining rightful stature for the Air Force EW program.

Electronic warfare should be an integrated part of the unit's combat capability. The EW officer must understand his unit's mission, and then apply EW principles and techniques to insure mission success.

Staff Duties

Detailed EW planning is seldom performed below wing level. Squadrons are chiefly responsible for execution of orders. Since EW officers must perform staff duties to carry out the planning and organization necessary to meet air operational requirements, they need training and experience for future staff work. This factor must be considered in setting up quotas and making selections for attendance at higher staff schools.

Job knowledge, while a primary prerequisite of a staff officer, is not enough. Staff officers must have the ability to communicate, organize, sell, and put into operation the policies and programs required to accomplish the command mission. The staff EW officer must be aware of the capabilities and limitations of EW personnel and equipment in subordinate commands.

Usually, the staff EW officer is a part of the headquarters operations staff and is considered to be an expert in his technical field. As such, it is his duty to keep the headquarters staff informed on all phases of electronic warfare.

The EW operations staff officer must assume the initiative and furnish the guidance to develop an optimum command electronic warfare program. It is his duty, therefore, to keep himself informed of the latest developments within his area of responsibility.

The EW staff officer must maintain current information concerning past, present, and future electronic developments in the United States and foreign countries. He must be on the distribution list for the highest level of EW information available to him, and he must, in many instances, compile his own technical reference file. He must also attend seminars and conferences pertaining to EW problems throughout the Air Force. He must know the status of equipment, training capabilities, limitations, and results of EW operations in all organizations under his headquarters. To gain this knowledge, he must visit subordinate units and acquaint himself with EW personnel and their problems.

INTELLIGENCE. An EW staff officer must maintain excellent coordination with the intelligence staff of his headquarters to insure familiarity with these major items of intelligence:

- Enemy electronic order of battle (EOB).
- Functions and capabilities of enemy control and guidance systems.
- Enemy frequency dispersal capability.
- Status and developments of the enemy electronic communications program.
- Status of the enemy EW program.

In addition, the EW staff officer must have knowledge of the friendly EOB to preclude interference and disruption of our electronic systems.

MATERIEL. The EW staff officer must coordinate and advise headquarters materiel staff personnel on matters pertaining to the logistics, maintenance, and supply support for EW equipment authorized the command. QRC or production EW equipment required by the command must be justified and approved by Headquarters USAF before it becomes a materiel support function.

OTHER DUTIES. The staff EW officer must prepare regulations which are required by his command, monitor the EW personnel program, and maintain liaison with other commands and services. He helps coordinate and maintain joint training exercises and operations employing electronic warfare.

Key personnel within the command should be indoctrinated in the capabilities and limitations of EW. Experience has indicated that attendance at the USAF EW familiarization course conducted at Mather AFB can be of great value in this respect. The EW officer should insure that all appropriate personnel are aware of and are invited to attend either Course 157000, Staff Officer Electronic Warfare Familiarization, or Course 157500, Staff Officer Warfare Refresher. Some EW officers may find it more appropriate to request "on-station" presentations of the EW familiarization course.

Wing EW Officer

The wing EW officer is a staff officer with duties similar to the ones outlined above. However, the wing EW officer's primary responsibilities shift toward implementation and training. His staff function is supplementary in nature, since he translates the directives of higher headquarters into action. Continued emphasis must be placed on training and maintaining proficiency in a tactical organization by the wing EW officer.

Squadron EW Officer

An electronic warfare officer acting as squadron EW officer is primarily a coordinator. The emphasis at this level must be constantly monitored to insure the highest standard of quality. The squadron EW officer is a member of the squadron operations section.

He must know the capabilities and limitations of the assigned EW equipment, and must be prepared to disseminate this information to the entire squadron. He must fully understand the EW tactics developed for his unit and recommend refinements and improvements when possible. He must continually strive to update his EW information by keeping abreast of the latest developments.

Job Description

To fully understand EW duties, a certain set of standards must be satisfied. The USAF has outlined these standards by the job description of AFSC 1575 in AFM 36-1. The job description is quoted for your guidance:

OFFICER AIR FORCE SPECIALTY
ELECTRONIC WARFARE OFFICER

1. SPECIALTY SUMMARY

Operates airborne defensive and electronic reconnaissance equipment, including electronic warfare, active defense, infrared and decoy systems; performs staff functions pertinent to active defense, electronic warfare, and electronic reconnaissance.

2. DUTIES AND RESPONSIBILITIES

a. Operates airborne active defense and electronic warfare equipment: Preflights analyzers, antennas, direction finders, panoramic indicators, receivers, recorders, repeaters, transmitters, chaff dispensing equipment, infrared countermeasures, active defense and decoy systems. Participates as a crew member in airborne missions. Operates special search, analysis, and other electronic equipment to obtain data on enemy electromagnetic equipment. Operates airborne electronic warfare systems to prevent effective operation of enemy ground and airborne electromagnetic weapon systems. Disrupts tactical communications data and control links associated with air defense interceptor and missile systems. Operates/supervises operation of inflight active defense systems in final phases of missile/interceptor attacks. Observes electromagnetic phenomena and tactics and logs data for future study and evaluation. Prepares mission reports, conducts service, suitability and operational tests of airborne electronic warfare and active defense systems and evaluates operational characteristics and effectiveness.

b. Plans tactical employment of airborne electronic warfare and active defense systems: Studies and analyzes intelligence reports, technical data, and other publications to determine requirements and capabilities of available electronic warfare and active defense equipments to counter the enemy air defense network. Studies and analyzes foreign electromagnetic developments, radar data, and electronic order of battle. Studies and analyzes foreign interceptor and missile defense data to develop optimum tactics and procedures to counter the threat. Plans electronic reconnaissance missions, assigns search priorities, and recommends routes to be flown. Plans and computes the type, quantity, and dispensing rates for chaff and infrared countermeasures materials. Prepares electronic warfare and active defense annexes to operations orders. Reviews past effectiveness of electronic warfare and active defense tactics and equipment. Develops or recommends development of improved techniques or equipment to neutralize the effectiveness of enemy offensive and defensive air defense systems.

c. Analyzes results of electronic warfare and active defense operations and prepares technical reports on data collected: Interrogates aircrew members, reviews logs of intercepted signals and evaluates data collected to determine future tactics and procedures. Compiles information and prepares technical reports on tactical employment of enemy offensive and defensive equipment, prepares studies on active defense and electronic warfare. Studies and plans application of electronic warfare techniques for aerospace purposes.

d. Supervises installation and operation and performs inflight maintenance of active defense, infrared, decoy, and electronic warfare equipment: Inspects electronic warfare, active defense, and associated equipment to determine operational condition and to insure operational effectiveness. Prepares standard operating procedures for equipment operation. Resolves technical problems encountered in installation and operation of equipment.

e. Plans, organizes, and conducts operational training for electronic warfare officers, defensive system operators, and other aircrew members. Determines requirements for training aids, simulators, and associated training equipment. Prepares training material related to intercept, analysis, confusion, and jamming of enemy electromagnetic activity. Prepares training materials relative to interceptor and missile capabilities, limitations, and attack geometry. Conducts lectures and demonstrations relative to evasive maneuvers and defensive procedures. Performs mission briefing of aircrew members on operating techniques and tactical capabilities of active defense and electronic warfare systems. Prepares and maintains pertinent training records and reports.

f. Performs staff functions relative to defense and electronic warfare activities: Exercises staff supervision over intercept operations, offensive countermeasures, active defense systems, and all other electronic warfare and penetrations aid activities. Advises intelligence activities in matters affecting collection, evaluation, and dissemination of electronic intelligence. Advises commanders and staff officers of all important changes and development in the active defense and electronic warfare field; problems affecting capability and efficiency; and recommends improved techniques and equipment. Prepares directives for guidance of subordinate activities. Remains fully familiar with all restrictions and procedures required to insure effective utilization of active defense and electronic countermeasures without conflicting with friendly operations. Coordinates with maintenance, personnel, supply, and other staff activities on matters relative to penetration effectiveness. Maintains current information on the clearance procedures necessary for conducting electronic warfare activities.

3. SPECIALTY QUALIFICATIONS

a. Education:

(1) Completion of college-level courses in algebra, theory of electricity and electronics, physics, and trignometry, is mandatory.

(2) Fundamental knowledge of air navigation and meteorology is mandatory.

(3) Completion of course in differential equations is desirable.

(4) Bachelor's degree in electrical engineering is desirable.

b. Experience: A minimum of 12 months' experience in airborne electronic warfare assignments is mandatory. It is mandatory that experience in electronic warfare, including active defense, include such functions as operating airborne equipment, developing tactics and techniques, analyzing results of operations, or preparation of plans, reports, or training materials.

c. Training: Completion of an electronic countermeasures course or an electronic warfare course at an Air Force school is mandatory.

d. Other: Current aeronautical rating and current flying status orders are mandatory.

4. SPECIALTY DATA

a. General Spread: Second lieutenant through lieutenant colonel.

b. Source Job (D.O.T.):
Electronic Engineer 0–17.01

CHAPTER 2

Radar Principles

Radar has advantages over visual and infrared techniques, especially within the earth's atmosphere. Radio waves penetrate fog and darkness, move at the speed of light, and are readily produced at high power levels. Sensitive receivers are capable of detecting signals at extremely low power levels. Radar performs many functions in modern warfare. However, identification and interference seriously reduce its capability.

It is possible to identify an individual radar by close observance and analysis of its emissions. All pulsed radar systems are similar, but to experienced electronic warfare personnel there are identifying characteristics for each type of radar system. These characteristics are determined to a large extent by the function that the radar is to perform and are extremely important to the EW officer.

After an electronic system has been designed and produced, the characteristics of its emissions are fixed. To change these characteristics usually requires a modification of the equipment. If this equipment appears in strategic areas, it may be readily identified, provided identifying characteristics have been previously recorded. If the characteristics of an observed radar are not known, much can be determined about its function through analysis of its emission characteristics.

THE NATURE OF ELECTROMAGNETIC ENERGY

A generalized but useful theory proposed by Maxwell states that a moving magnetic field creates an electric field, and a moving electric field creates a magnetic field. The parent field is in time phase at any instant with the created field, and both are mutually perpendicular in space. These electromagnetic waves, then, are propagated as transverse waves having oscillating motion at right angles to the direction of propagation. Some of the basic terms describing wave phenomena may be defined as follows:

Radio wave propagation refers to the movement of radio waves through any medium.

Period of oscillation is the time required to complete one cycle.

Frequency is the number of cycles completed in one second.

Amplitude of oscillation is a measure of the maximum displacement of the wave from its null or undisturbed condition.

Wavelength is the distance the wave will travel in the time of one cycle.

In phase occurs when two or more waves of a common frequency passing through the same point reach their maximum amplitudes in the same direction at the same time.

Phase opposition occurs when two waves passing through a common point reach their maximum amplitudes in opposite directions at the same time.

Velocity of propagation of electromagnetic energy is approximately 300,000,000 meters (or 186,000 miles) per second.

MODULATION

Modulation is defined in most text books and technical manuals as the process of impressing intelligence on an electromagnetic wave. While this definition is valid for communications and other electronic applications, it does not apply for electronic countermeasures. The objective of countermeasures is to prevent the enemy from gathering and disseminating usable information. The type of modulating signal employed in any instance depends upon the nature of the signal to be countered. The most commonly used modulating signal in ECM operations is random noise.

Major types of modulation may be placed in four basic groups, which are:

Amplitude Modulation. This process impresses intelligence on a radio wave by varying its power.

Phase Modulation. The intelligence is conveyed by changes in the phase angle of the radio wave. This form of modulation is seldom used in countermeasures equipment.

Frequency Modulation. The process of varying the frequency of a constant amplitude radio wave in accordance with the intelligence to be transmitted.

Pulse Modulation. Type of modulation in which energy is grouped into certain chosen intervals or pulses and is absent from other intervals. The modulation in the signal is carried by a change in location, amplitude, number, duration, or shape of the pulses in response to the intelligence being transmitted.

BASIC RADAR PRINCIPLES

Radar is defined in AFM 100–39, *Communications Terminology*, as "equipment that determines the distance and usually the directions of objects by transmission and return of electromagnetic energy." In general, equipment that locates or detects objects by reflections of electromagnetic energy to derive information concerning the object is referred to as radar. Information concerning the detected target may be range, direction, height, velocity, identity, or any combination of these.

CW Systems

An elementary CW Doppler system is shown in figure 2–1. Such a system contains a transmitter, receiver, indicator, and appropriate antennas. The antennas are normally directional.

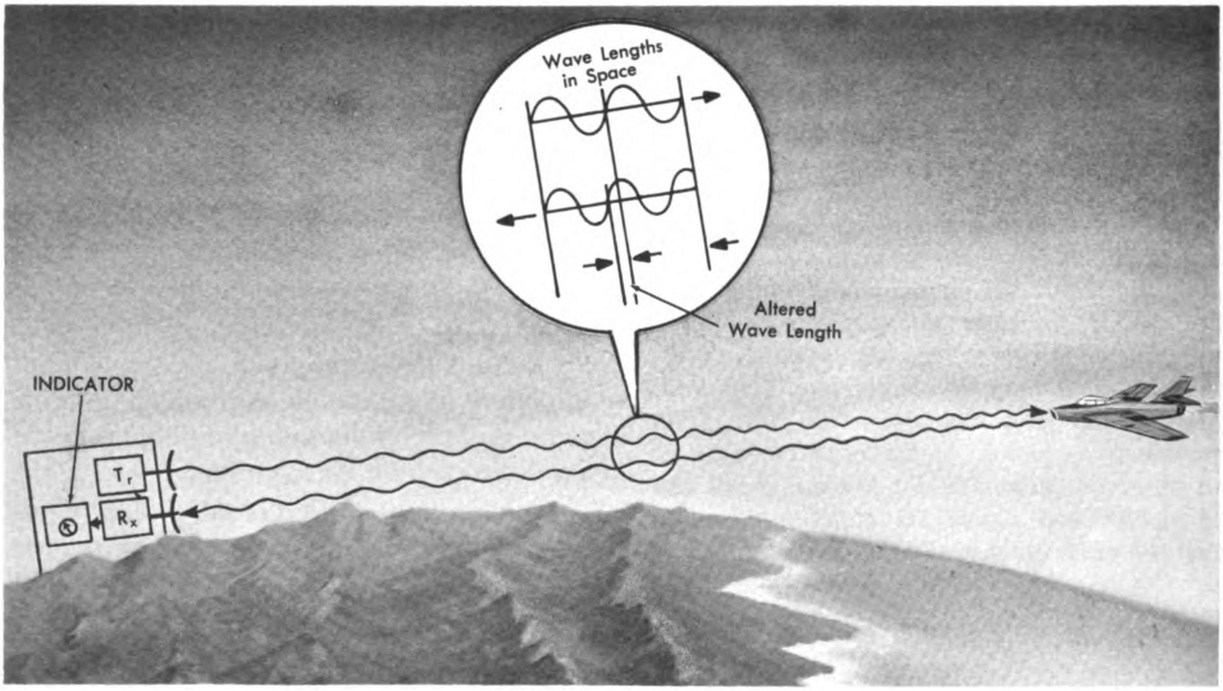


Figure 2–1. *CW Doppler Radar*

This type of radar system depends on the Doppler frequency shift for detection of the reflected signal. The transmitted radio energy is radiated from the transmitter antenna, strikes a target, and returns to the receiving antenna. It is then sent to the receiver where some spillover energy from the CW transmitter is mixed with it. If the frequency of the reflected signal has been altered, there will be a detectable difference between it and the transmitter frequency. This difference frequency is amplified and sent to the indicator. There the signal is converted to an average current proportional to the frequency change of the reflected signal. The following discussion describes the Doppler frequency shift caused by an aircraft.

The Doppler effect is defined as a phenomenon evidenced by the change in the observed frequency of a wave in a transmission system caused by a time rate change in the effective length of the path of travel between the source and the point of observation. This is illustrated in figure 2–1. As the wave fronts strike the moving target, the target continuously reflects energy back to the receiver. The effective path traveled by the wave is from the transmitter to the target and back to the receiver.

The Doppler frequency shift amounts to about 30 cps per 100 mc for each 100 mph of target speed. The indicator of a Doppler radar may be calibrated directly in speed, provided the radar is on a collision or near-collision course with the target, or if the target is moving directly away from the radar.

Use of the CW Doppler type radar is limited because of its inability to determine range or to detect fixed targets. Another limitation is the difficulty in obtaining the extremely high peak power required to produce detectable echoes from distant targets.

Frequency Modulated Systems

The range measuring inability of the elementary Doppler system may be overcome by frequency modulation of the radiated wave. Such a system does not depend on the Doppler frequency shift, but requires that the target reflect part of the energy back to the receiver.

The range to a reflecting target is determined by the time required for a cycle to reach the target and return. The amount of

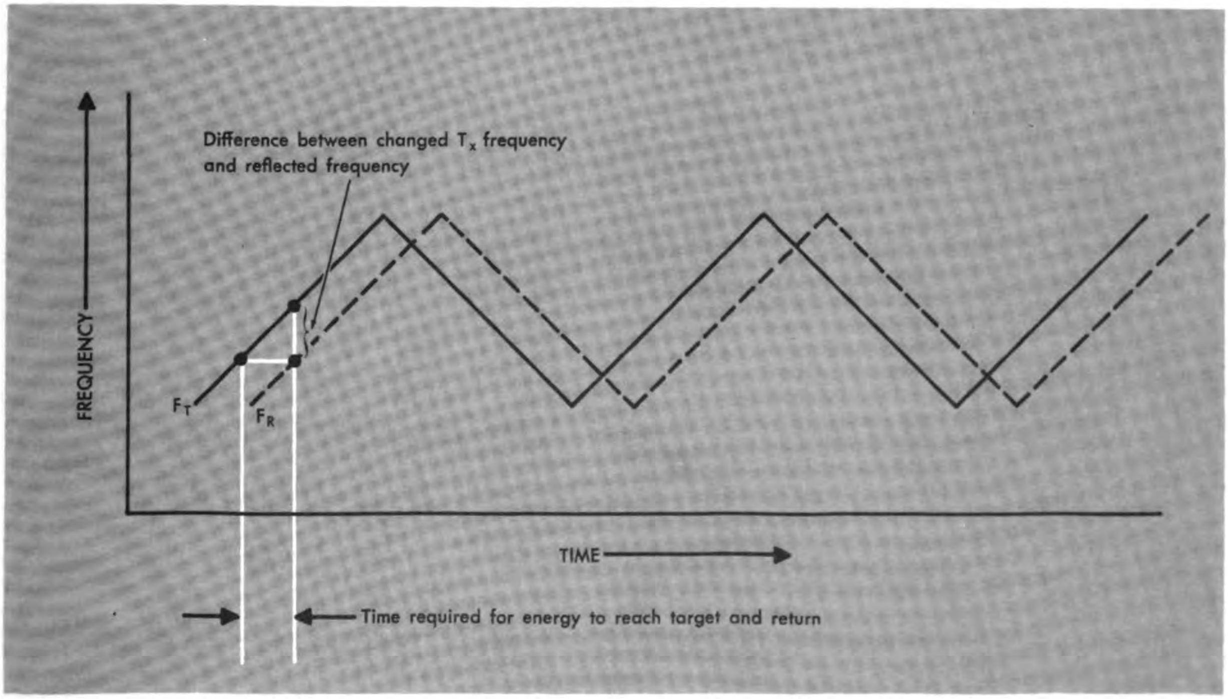

Difference between changed T_x frequency and reflected frequency
FREQUENCY
F_T
F_R
TIME
Time required for energy to reach target and return

Figure 2–2. *FM Radar Frequencies*

transmitter frequency change during echo time determines range. The transmitted wave in a frequency modulated signal retains its frequency as it travels to the target and back. As a given cycle is traveling to the target and back, the transmitter is constantly changing frequency. The amount of frequency change in the transmitter before the return of a given cycle is determined by the time required for the energy to reach the target and return and the rate of change of the transmitter frequency. A small amount of the transmitter energy is allowed to leak over into the receiver where it is mixed with the reflected signal.

If the target range remains constant, the time for the reflection of the returning frequencies is fixed as shown in figure 2–2. The difference (beat frequency) between the reflected frequency (F_r) and the transmitter frequency (F_t) is detected and amplified in the receiver. This difference frequency is proportional to the time of echo; thus, the range of the target is proportional to the frequency difference of the reflected frequency and the transmitter frequency.

The maximum range of an FM radar is limited by the amount of power the transmitter can produce and the frequency of modulation. FM radar systems can detect targets at very short ranges in the order of a few yards. There is no powerful main pulse to obscure the readings at very short ranges.

Pulse Systems

The essential components of a pulse radar as shown in figure 2–3 are:

1. A *power source* to produce transmitter high voltages.
2. A *modulator* for forming the basic pulse characteristics.
3. An *RF generator* having high power capability for conversion of the modulator DC pulse to RF energy.
4. An *antenna* for radiation and reception of pulsed RF energy.
5. A *sensitive receiver* for amplification and detection of the weak echoes.
6. An *indicator* for display of the echo pulse.

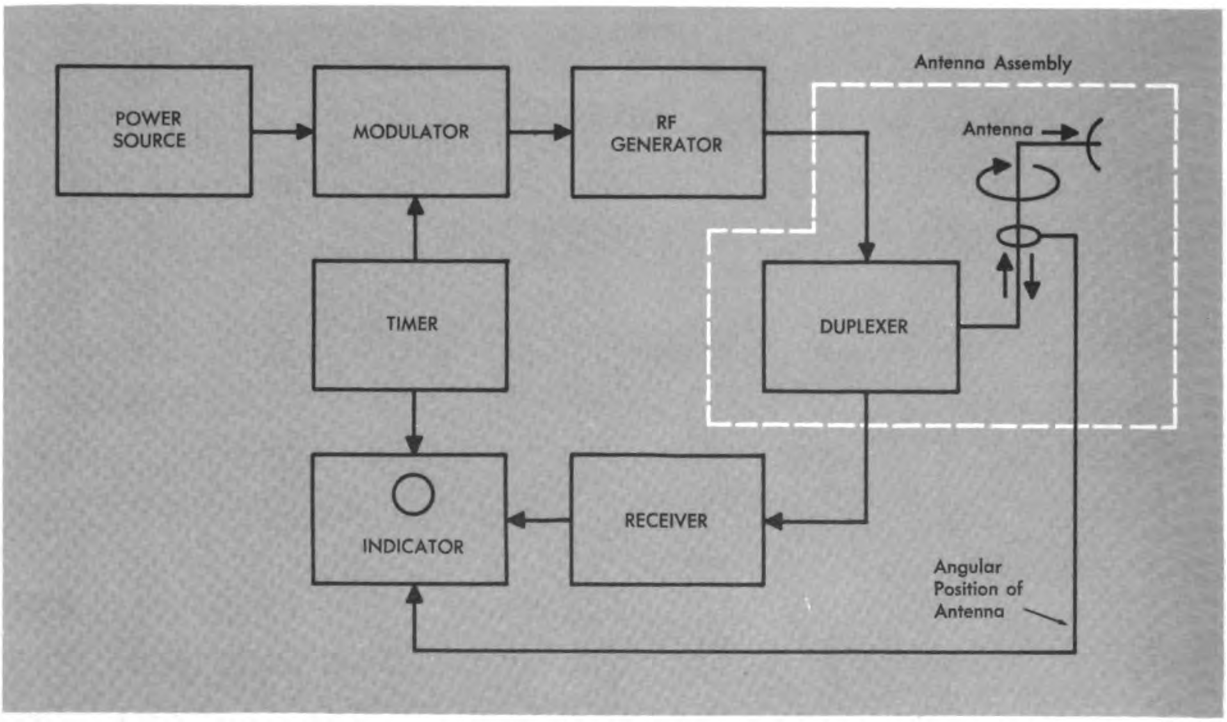


Figure 2–3. *The Basic Pulse Radar Components*

7. A *timing circuit* to synchronize the transmission of the pulse and the beginning of the timing cycle in the indicator. Also, the timing circuit in most radar systems generates accurately timed range references (range markers) for the indicator.

8. An *electromechanical means* for generating angular information of the antenna position.

The transmitted RF pulses strike a target in space, inducing a current in the target. This current causes radiation from the target in many directions. A minute part of the energy is reflected back to the antenna and into the receiver. The receiver amplifies the weak echo and converts this RF energy into a DC pulse of current or voltage. The detected pulse is amplified and displayed on a cathode-ray tube (CRT) indicator in a manner that allows an observer to readily determine the range to the target.

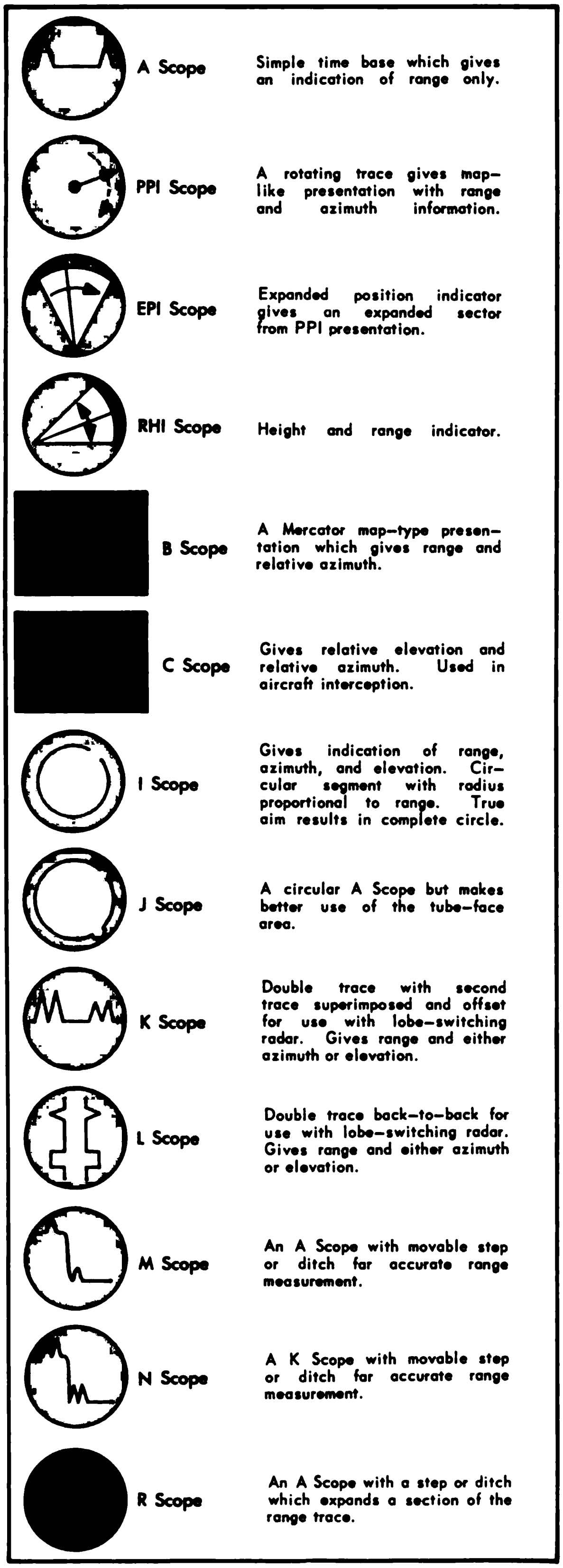
The type of indication or presentation utilized by a radar set is determined by the information desired. Many types of radar indicators have been devised. The most common type of indicator is the cathode-ray tube. The CRT may present a simple time base for the measurement of range, or it may chart an area by tracing a picture in much the same manner as television.

An EW officer should be familiar with the types of scopes shown in figure 2–4.

The pulse system of radar may be designed to generate RF energy at extremely high power (peak power), which makes long-range operation possible. This, plus its adaptability to almost any search or tracking problem, makes it the prime type of radar developed and used by all military forces of modern times.

TECHNICAL CHARACTERISTICS OF A PULSED RADAR

The characteristics of a pulsed radar system are built into the design of the equipment according to its intended use. The requirements for a given set include the detection of a desired target and the accurate determination of its position at a specified range. Other specifications may be added, such as the ability to separate targets and the speed of collecting data. These requirements are re-



A Scope	Simple time base which gives an indication of range only.
PPI Scope	A rotating trace gives map-like presentation with range and azimuth information.
EPI Scope	Expanded position indicator gives an expanded sector from PPI presentation.
RHI Scope	Height and range indicator.
B Scope	A Mercator map-type presentation which gives range and relative azimuth.
C Scope	Gives relative elevation and relative azimuth. Used in aircraft interception.
I Scope	Gives indication of range, azimuth, and elevation. Circular segment with radius proportional to range. True aim results in complete circle.
J Scope	A circular A Scope but makes better use of the tube-face area.
K Scope	Double trace with second trace superimposed and offset for use with lobe-switching radar. Gives range and either azimuth or elevation.
L Scope	Double trace back-to-back for use with lobe-switching radar. Gives range and either azimuth or elevation.
M Scope	An A Scope with movable step or ditch for accurate range measurement.
N Scope	A K Scope with movable step or ditch for accurate range measurement.
R Scope	An A Scope with a step or ditch which expands a section of the range trace.

Figure 2–4. *Radar Indicators*

solved in the four basic characteristics: pulse, RF, antenna scanning, and indicator.

The *pulse characteristics* determine the range limitations. The *RF characteristics* affect the precision of measuring the angular coordinates and the maximum range of the equipment. *Antenna scanning characteristics* determine the angular coordinates, while the *indicator* displays the target relative to distance and angle. The antenna scanning and the indicator characteristics combine to make the target information readily available for a given use.

Pulse Characteristics

The terms describing pulse characteristics are:

- *Peak power* (P_{pk}) is the maximum level of power.
- *Pulse width (PW)* is the time duration of the pulse as measured at the half-power points.
- The *pulse repetition frequency (PRF)* is the number of pulses generated per second. This is sometimes referred to as the Pulse Recurrence Rate (PRR).
- The *average power* (P_a) of the wave is the total power divided by the total time of the wave. The average power of one cycle of the PRF is the peak power times the pulse width divided by the time of one cycle.
- The *pulse recurrence time (PRT)* is the time of one complete cycle, and is the reciprocal of the PRF.

Performance Characteristics Related to Pulse Specifications

The pulse width limits *minimum range.* Since the transmitter signal is many times stronger than any echo, it must be turned off before an echo may be distinguished from the transmitter pulse. This means that no signals can be received from targets closer than one having a reflecting interval (time to the target and back) equal to the pulse time. For example, if the pulse width (PW) is 1 μS, then all targets closer than 492 feet will be obscured by the transmitter pulse.

The pulse width also determines the ability of the radar to separate two targets having the same bearing, but at different ranges. The pulse in free space has a real length equal to the time of the pulse multiplied by the velocity of propagation.

In figure 2–5 the targets in A are separated by one-half the pulse length. T_2 in illustration A shows the pulse one-half microsecond after first encountering the target. At this time the echo from the first target is 246 feet long. T_3 shows the pulse slightly beyond the first target. Note that the echo from the second target is joining the echo from the first target. Combined echoes of this nature will show a single pulse on the indicator; therefore, targets separated by only one-half the pulse length or less will not be resolved in range. If targets are separated by a distance slightly greater than one-half of the pulse length, they may be readily resolved, as shown in illustration B.

The PRF is determined by the maximum range of the radar. The transmitter must remain quiet during the complete listening time for at least two reasons. First, if it were to fire as an echo is returning, the echo would be lost. Second, if the transmitter is allowed to fire a second time before the echo returns, received echoes could not be identified since it is impossible to determine which transmitter pulse was the reference pulse (assuming the pulses to be uncoded). Thus the range could not be determined due to ambiguity. This means that the transmitter pulse must be timed so that the PRT is greater than the time required for echoes to return from the maximum possible range.

Another important consideration concerning the PRF is the *scanning rate.* The rotational speed of the antenna (scanning rate) is limited by the pulse recurrence time (PRT) just as the minimum PRT is limited by the maximum range of the radar. If the antenna is rotating too fast, insufficient echoes will be received.

In radar equipment designed for long-range detection, the scanning rate must be slow enough for a sufficient number of echo pulses to be received from a given target to produce the proper spot intensity on the CRT indicator. If the system is designed for short-range detection, it will have a much higher scanning rate. The antenna scanning rate, therefore, is an important clue to the function of a particular radar system.

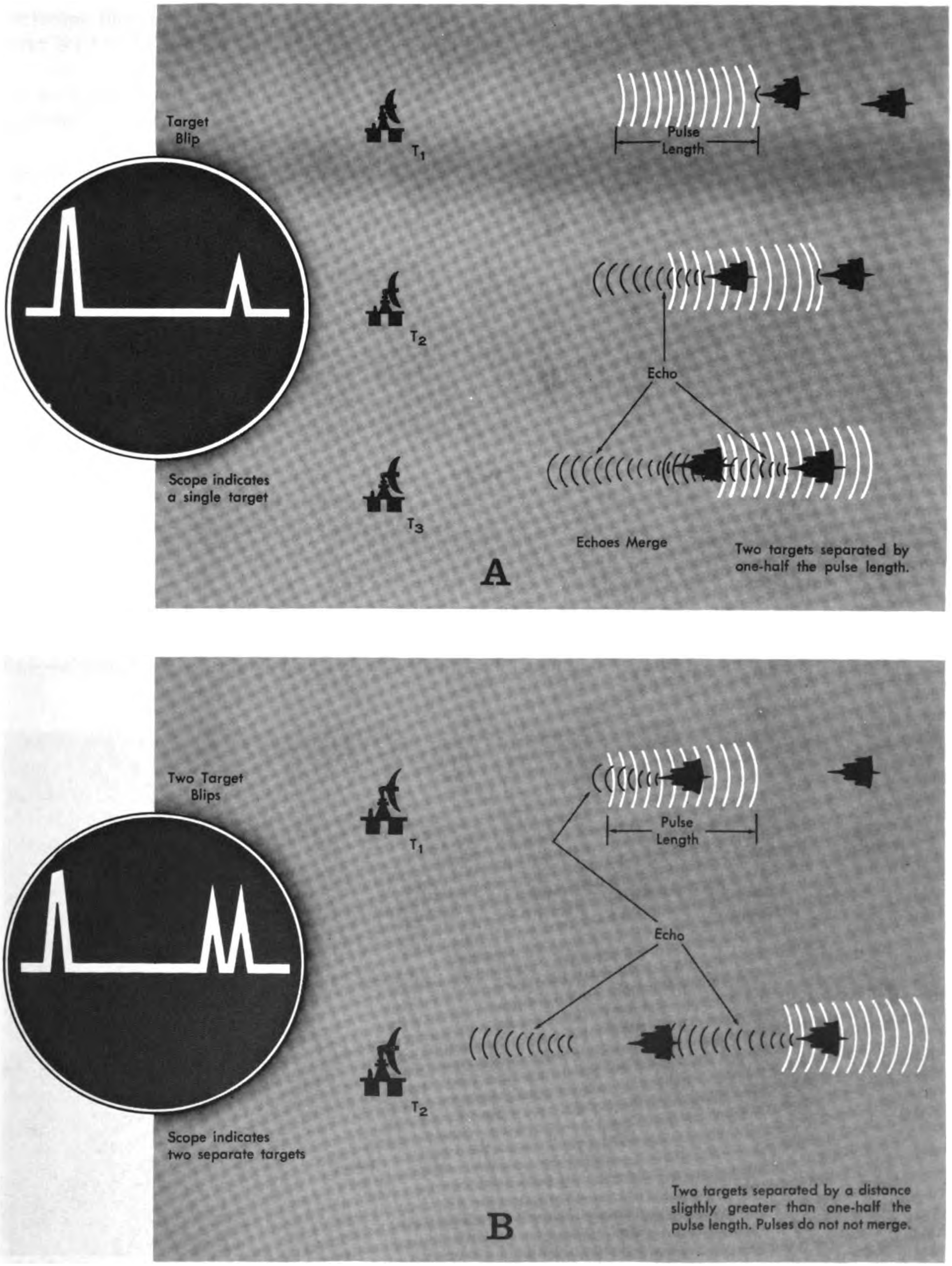

Target Blip
T1
Pulse Length
T2
Echo
Scope indicates a single target
T3
Echoes Merge
Two targets separated by one-half the pulse length.
A
Two Target Blips
T1
Pulse Length
Echo
T2
Scope indicates two separate targets
Two targets separated by a distance sligthly greater than one-half the pulse length. Pulses do not not merge.
B

Figure 2–5. *Pulse Radar Range Resolution*

Transmitter Frequency

The frequency of a radar set affects several operating characteristics. One of the prime requirements of radar is a narrow beam of energy. To radiate a narrow beam of energy, the wavelength must be short in comparison to antenna size. Also, the higher the frequency, the narrower the beam for a given antenna size. Because of this property, high frequencies are generally preferred in precision radars.

On airborne pulse radar installations, antenna size is especially limited, and these radars are forced to operate above 3000 mc. With ground radars, antenna size is not critical and operating frequencies of precision radars can go as low as the VHF band.

The operating frequency of the radar is related to the transmitter power and receiver sensitivity. These performance characteristics are degraded by attenuation and power limitations as the frequency is increased. The maximum range of radar equipment tends to decrease as the operating frequency is increased, if other factors remain about equal.

Interference patterns occur in low frequency radars due to surface reflections. Figure 2–6 shows the paths of the direct and reflected waves. Strong lobes, as illustrated, are produced by the addition of these two waves. The nulls between strong lobes are a result of cancellation of the direct and reflected waves.

The strong lobes increase the range of the radar. The nulls between the lobes are a disadvantage, however, since targets may be lost when passing through this part of the radiation pattern. Interference effects may be reduced or eliminated by using higher frequencies which narrow the beam and raise the electrical height of the antenna.

Many factors are considered when selecting a frequency for a specific performance requirement. But one of the most important considerations is the need for multiple frequency capability. Without this capability, all the defensive radars of a country would be easily neutralized by ECM.

Radar Scans

The primary function of a radar determines the scan of its antenna. An early warning radar must give coverage in all directions and

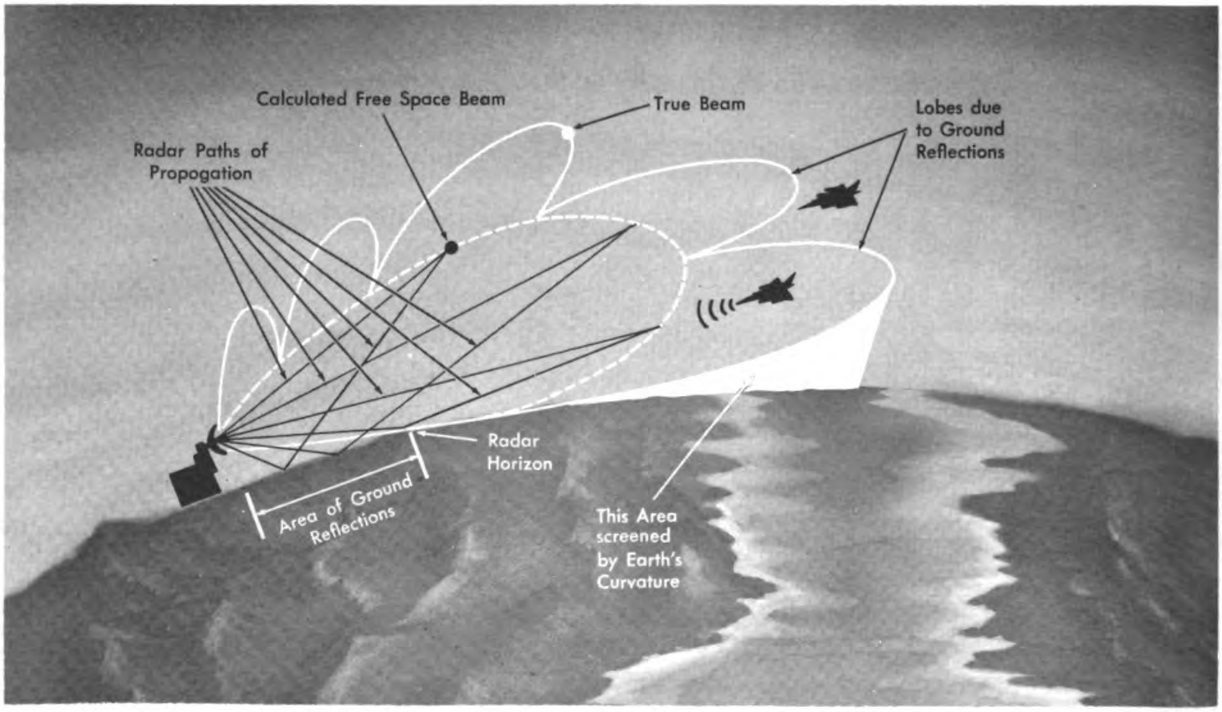

Calculated Free Space Beam
True Beam
Lobes due to Ground Reflections
Radar Paths of Propogation
Radar Horizon
Area of Ground Reflections
This Area screened by Earth's Curvature

Figure 2–6. *Ground Reflections from a Radar Antenna*

therefore uses a circular scan. Circular scans are produced by a continuous 360° rotation of a vertically oriented fan-shaped beam.

Such a scan does not provide an indication of height but does determine the azimuth of the target. Rough indication of height may be derived in long-range search radar by special antennas that divide the shape of the fan into vertical segments (separate lobes or beams stacked one above the other).

Some radar sets give the azimuth, elevation, and range of a target while maintaining a circular scan. This is accomplished by means of a V beam. The antenna radiates two beams set on slightly different azimuth angles. One of these beams has its greatest dimension in the vertical plane, while the second is inclined at a 45° angle from the vertical. These beams would look as shown in figure 2–7.

Since the two beams rotate together, every target returns two echoes, and the higher the target, the greater the time interval between echoes.

Height-Finder Radar Scans. The primary difference between height-finder radar and search radar is that the height finder scans a sector in the vertical plane. To accomplish this, the antenna "nods" up and down. This type of vertical sector scanning is shown in figure 2–8.

A height-finding radar in conjunction with a search radar provides ground controlled interception (GCI) capabilities. To guide an interceptor to a successful contact with a target, ground radar personnel must know the direction, range, and altitude of the target. The height finder provides the altitude information.

A target at a range of 35 miles and an altitude of 25,000 feet will appear on an RHI scope as shown in figure 2–8. It can be seen that the RHI scope presents an indication of the target's altitude plotted against its range.

Precision Radar Scans. There are two techniques for measuring angular coordinates in radar operations, the maximum echo method and the minimum echo method.

The maximum echo method simply requires that the operator move the antenna across the target until maximum echo is returned. This technique is easy to accomplish, but does not yield the best accuracy since the changes

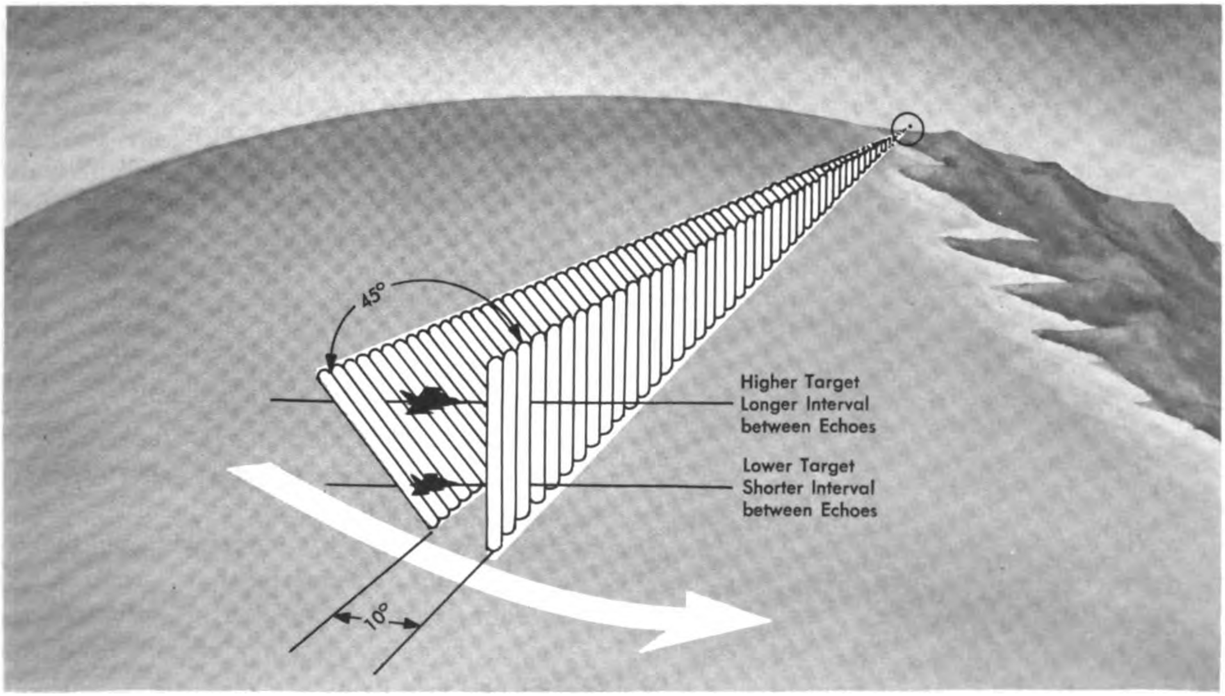


Figure 2–7. *V-Beam Radiation Pattern*

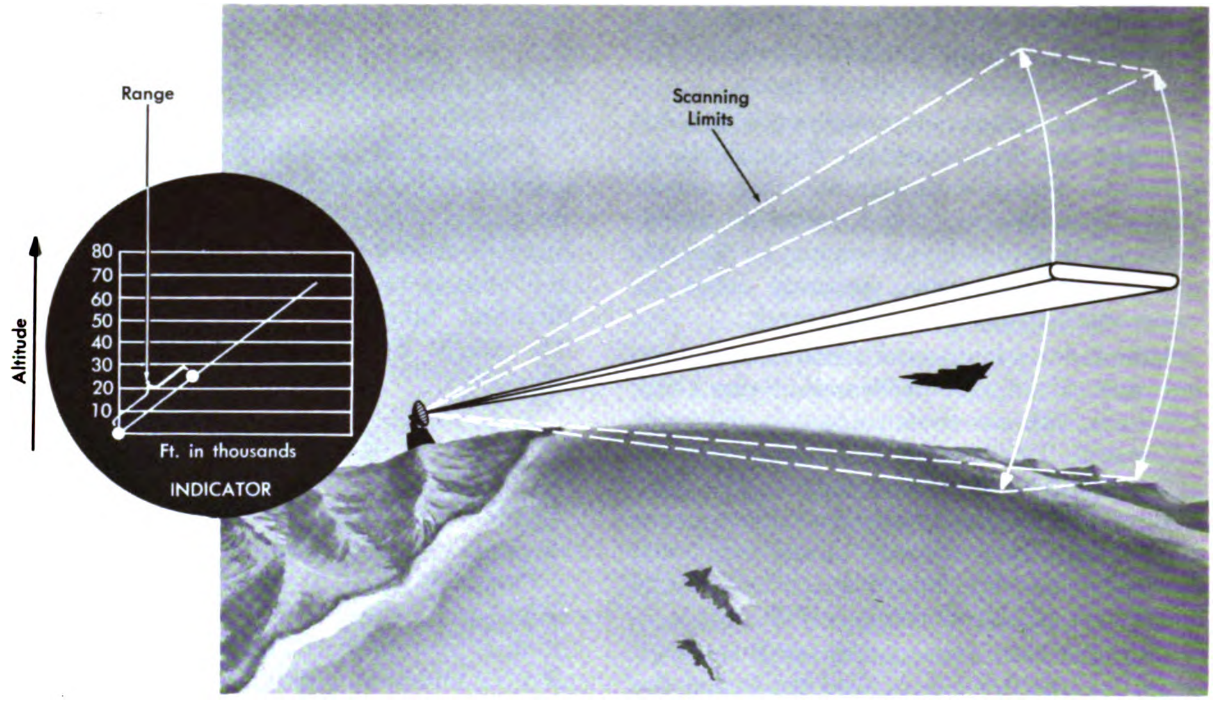


Figure 2–8. *Height-Finder Radar Scan*

of signal strength are small at angles near the center axis of the beam.

The minimum echo method depends on the rapid change of signal strength at the outer or extreme angles of the beam. Two readings are taken, one for each side of the beam at a point of equal response. The bearing of the target will be midway between the two readings.

Precision radar utilizes the minimum echo method but simplifies the operator's job by introducing either lobe-switching techniques, conical scan, or monopulse systems.

The *lobe-switching* antenna scan produces two slightly overlapping beams. By alternating lobes, echoes from opposing beams are produced and displayed on a common indicator for comparison. The angular position of the target can be determined by equalizing the relative amplitude of the responses from the two beams.

The *conical scan* is an improvement of the lobe-switching technique. Conical scan systems use a single beam that is rotated about the center of the scanning axis. Angular readings are made along the inside edge of the lobe as in the lobe-switching technique; however, the conical scan rotates about the target, providing both azimuth and elevation readings simultaneously. The conical scan is readily adapted to automatic tracking systems.

The *helical* scan allows a narrow-beam radar to be raised vertically as the antenna rotates. The beam describes a spiral in space. Complete area coverage is obtained by overlapping the scans. The helical antenna scan provides range, azimuth, and elevation. Helical scans may be combined with conical scans in a "search" mode in precision radars.

Another precision radar scan is called *monopulse*. This method provides faster and more accurate data for tracking targets and is an improvement over conical scan. The term monopulse does not mean that only one pulse is transmitted; it means that, from just one pulse of energy, the returned echo will contain sufficient information so the antenna can position itself correctly for tracking the target. The monopulse operation can be found on aircraft fire control systems and precision target tracking systems.

Figure 2–9 shows the component parts of the radiator of such a system. A monopulse

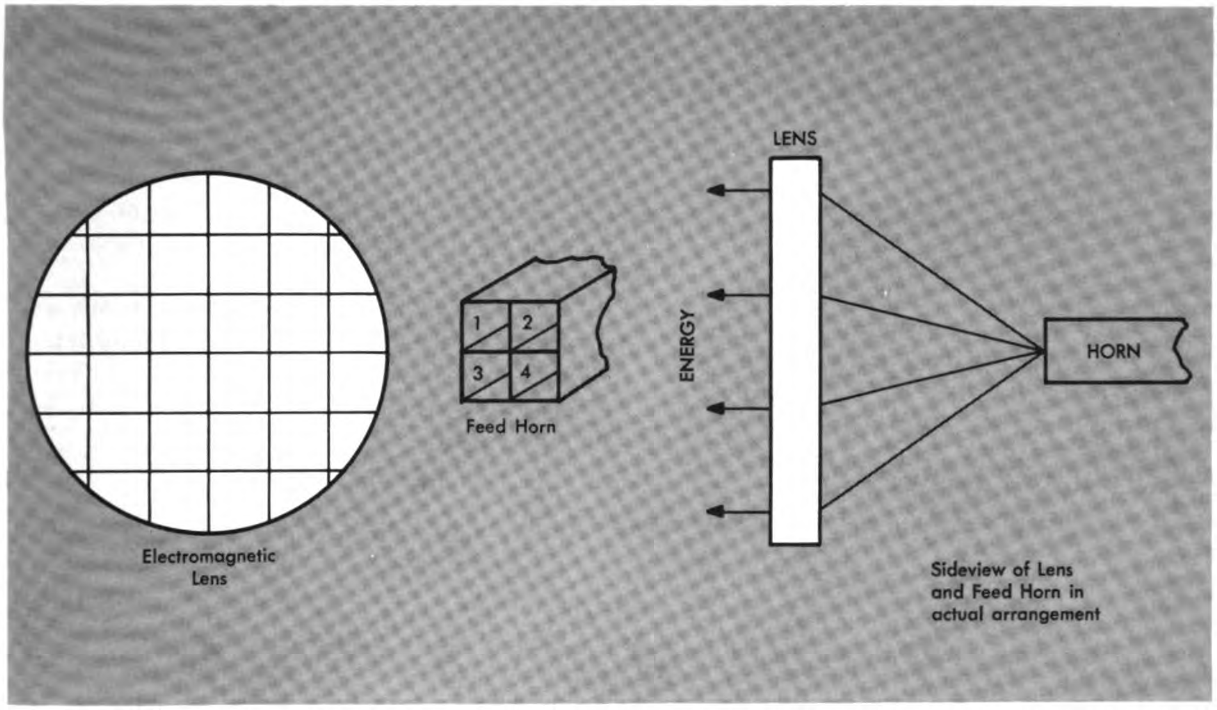


Figure 2–9. *A Monopulse Radiator*

radar is characterized by a steady tone, a high PRF, and a narrow pulse width.

Beam Width Error. One type of scanning error is caused by the horizontal beam width. When a beam of electromagnetic energy passes through space, it momentarily illuminates any targets lying in the path of the beam. Assuming that the antenna beam is 3° wide, then all pulse echoes from each 3° sector appear on their respective sweeps along the trace. The presentation on the scope therefore appears as an arc 3° wide, with its center lying on the azimuth bearing corresponding to the direction of the target. Thus, any target appears wider than it actually is by a factor equal to the width of the beam. This error is called beam width error.

Indicator Errors and Limitations

The minimum spot size that can be shown on the CRT display is the cause of another type of error. Every CRT presents information by means of a stream of electrons which strike a fluorescent screen and cause it to glow. The accuracy with which detailed information can be presented depends on fine focusing of the electron beam. The very best of focusing results in a bright spot on the screen which is at least 1/30 inch in diameter. The inaccuracy of presentation caused by the physical size of the luminous trace is called spot-size error.

A metal roof or the concrete wall of a building offers an excellent reflecting surface to radio energy. If the surface is perpendicular to the radiated beam it will reflect most of the energy; if it lies at an angle of less than 90° to the beam, the energy is deflected off in another direction. Thus the radar in an aircraft approaching a city (where buildings are built "square with the world") from one of the cardinal points, will receive sharper, stronger echoes than from other directions. While this cardinal point effect does not constitute an error, it will determine the character of the radar presentation.

Radar operators sometime receive a false impression of target size because the target is resonant to the radar frequency. The echo response from a resonant target is much greater than the response of an ordinary target.

The actual range of a radar set may suffer considerably because of malfunctions due to poor maintenance. If the modulator does not form a properly shaped pulse, the transmitter efficiency decreases, reducing the effective signal strength and range. If the receiver has not been properly aligned, it will have poor sensitivity, thus reducing maximum range.

FACTORS AFFECTING ACTUAL RADAR DETECTION RANGE

The relationship of the radar equipment factors affecting the actual maximum range of a radar set are defined in the radar-range equation. To derive this equation, all influencing factors outside the radar equipment and the target have been removed. This means that the equipment and target would be located some distance in space, free of reflections from the earth's surface. Although this is a theoretical situation, the "free-space radar equation" gives an excellent overview of basic factors affecting actual range.

The Free-Space Radar Range Equation

Since the effectiveness of a radar set depends on the detection of a weak signal returned from a distant reflecting object, the factors which control the strength of the echo are of first importance. To work out the radar equation, the properties of the transmitting and receiving antenna systems must be known. So must the reflection characteristics of the target. In addition, the losses encountered in radiation through space must be computed. Another important factor is the determination of the minimum signal strength which the receiver will detect.

RECEIVER SENSITIVITY. The sensitivity of a receiver is a measure of its ability to pick up a weak signal and present a usable output. This minimum sensitivity, or S_{MIN}, is defined as the minimum signal power required for detection.

ANTENNA GAIN. This is a measure of the ability of the antenna array to concentrate its radiated energy into a narrow beam. Such narrow concentrated beams are characteristic of microwave radar. Microwave radars require antennas that are large compared to wavelength; that is, they require antennas with high gain.

COEFFICIENT OF TARGET REFLECTION. Since radar depends on echoes for its signals, the ability of the target to reflect energy is of prime importance in the radar equation. This ability to reflect is seldom a constant, and only in special cases can it be calculated accurately. An aircraft reflects a varying amount of energy, depending not only on its size but also on its target aspect.

RADAR EQUATION. Now that the terms are defined, they may be related to one another.

P = power radiated
A = area of the antenna
G = antenna gain = A/λ^2
σ = coefficient of target reflection
S_{MIN} = minimum sensitivity of the receiver (minimum reflected power that will cause a detectable signal at the indicator)
R = range

The relation of these factors affecting the actual maximum range of a radar is now available.

The equation is:

$$R = \sqrt[4]{\frac{\sigma P A^2}{16\pi^2 \lambda^2 S_{MIN}}}$$

Line-of-Sight Limitations

The free-space radar range of a specific set as determined by the preceding radar equation is not the only factor that affects actual maximum range. Another factor is the limitation imposed by the line-of-sight transmission of microwave radars. Since the information necessary for solving the radar equation is very often difficult to obtain, radar coverage for practical purposes may be obtained by determining the line-of-sight limitations.

There are various methods of obtaining radar (or line-of-sight) coverage data. The method used depends on the particular situation.

RADAR HORIZON DISTANCE (RHD). According to the line-of-sight concept, the maximum range of radar waves is limited by obstructions. The obstruction that is always present is the horizon. Since the height of the antenna and the height of the target extend the horizon, they are important factors in extending the maximum range.

The line of sight distance to the horizon from an antenna above the earth's surface is called

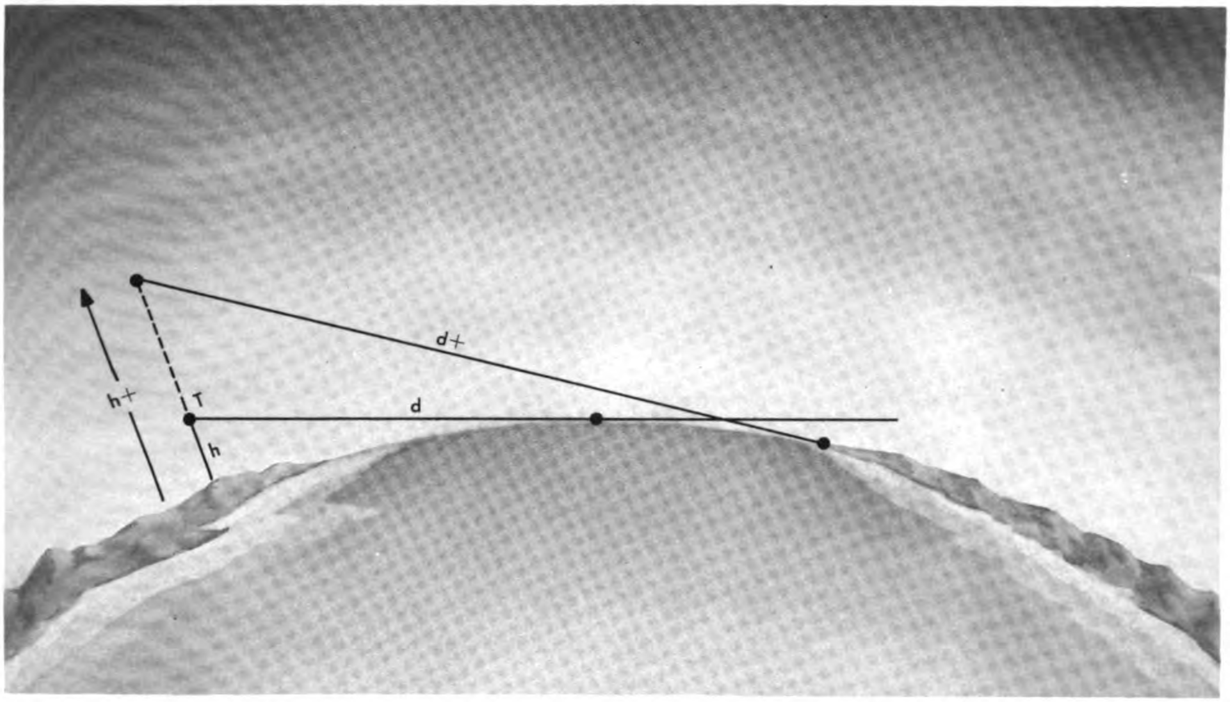


Figure 2–10. *Radar Range with Elevated Antenna*

the optical horizon distance. If the antenna height (h) is increased as shown in figure 2–10, the horizon distance (d) will be increased (d+), but not in direct proportion. Since the antenna is perpendicular to the earth's surface, it can be considered as an extension of the radius of the earth. With d expressed in miles and h in feet, the formula is:

$$d = \sqrt{1.5\,h}$$

Increasing the altitude of the target would have a result similar to that of increasing the height of the antenna. This is illustrated in figure 2–11. In the illustration the points are:

P_1 = top of antenna
P_2 = tangent point
P_3 = target
a = altitude of target

D is the horizon tangential distance to the target. Since the formula for this distance must include consideration of the altitude of the target, the formula for D along an optical path is:

$$D = \sqrt{1.5h} + \sqrt{1.5a}$$

The formula previously mentioned is for the optical horizon. It does not take into account the refraction or bending of radar waves around the curvature of the earth. This phenomenon is always present to some extent, depending upon prevailing atmospheric conditions.

Experiments have proved that radar horizon distances are approximately 1.33 times as great as those obtained using the equation for optical horizon. Making necessary computations, the radar line-of-sight equation is:

$$D = \sqrt{2h} + \sqrt{2a}$$

Control Point. An obstacle in the path of a radar beam will cause a shadow directly behind the obstacle. An aircraft in this shadow area will not be detected by the radar. To determine the extent of shadow caused by an obstacle, draw a straight line from the radar antenna through the point in the obstacle that gives the greatest angle with the horizon. In figure 2–12, note that only the portion of the obstacle that is above the RHD line to the horizon produces a shadow area. Note also that the greatest shadow is not necessarily caused by the closest obstacle.

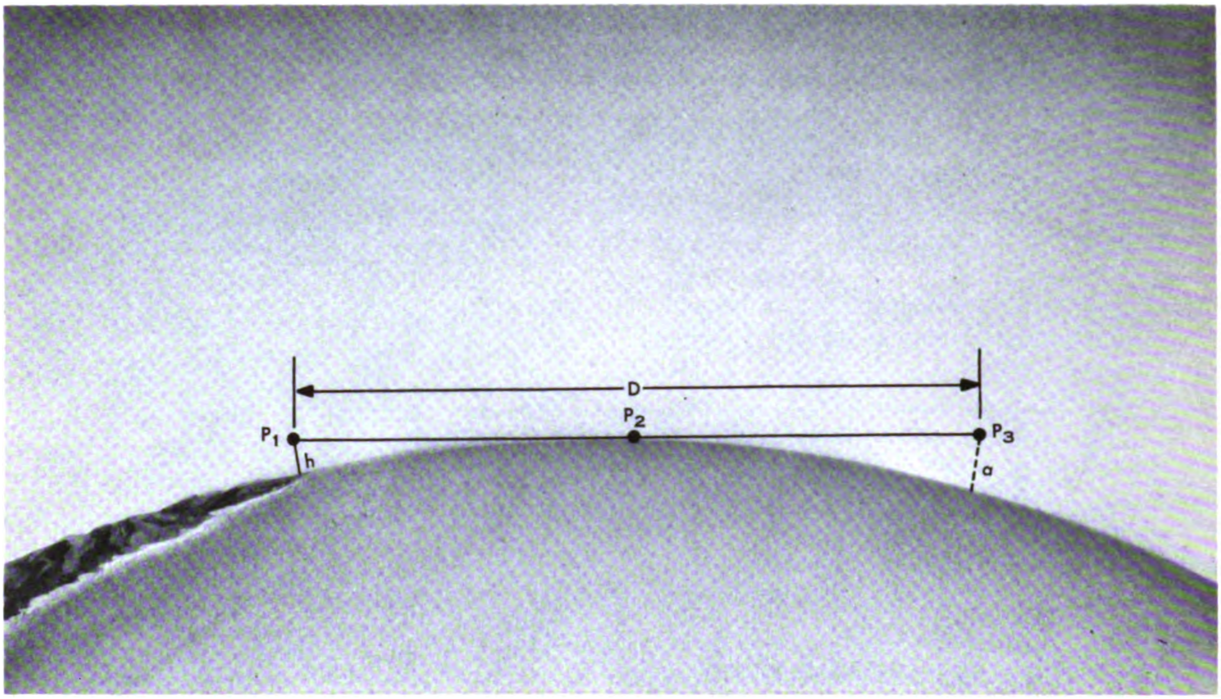


Figure 2–11. *Distance from Antenna to Target*

Where there is more than one obstacle in a given direction, as in the case illustrated, the obstacle having the greatest effect on the radar beam is known as the control point. This control point must be determined in order to compute the detection distance of a radar in that direction (see figure 2–13).

The formula for computing the radar detection distance is:

$$D = (d - o/c) + \sqrt{2(a - h) + (d - o/c)^2}$$

Where h = height of antenna in feet

o = effective height of obstruction in feet = $e - \frac{(d - c)^2}{2}$

c = distance from antenna to control point

d = distance antenna to horizon in miles

a = altitude of target in feet

This equation is the one that is used in the construction of a radar coverage map. The exact location of the radar must be known and a contour map of the area must be available.

Chart Construction. The procedure for chart construction is as follows:

1. Pinpoint the location of the radar on the contour map.
2. From the radar site draw radial lines spaced 10 degrees apart.
3. For each radial line find the heights of all obstructions and their distances from the radar.
4. From this information determine the control point, making use of the following formulas:

$$d = 2h$$
$$x = (d - 2)^2$$
$$o = e - x$$

The terms used in these formulas are shown in figure 2–13. There will be one control point for each radial line.

5. Find the detection distance at the desired altitudes for each radial line with the formula:

$$D = (d - o/c) + \sqrt{(d - o/c)^2 + 2(a - h)}$$

6. Connect the detection distance points on each radial line for corresponding altitudes.

Nonstandard Propagation

Radar waves are not always propagated in the same way. It is highly desirable that the EW officer be familiar with nonstandard wave propagation so that he will be able to identify

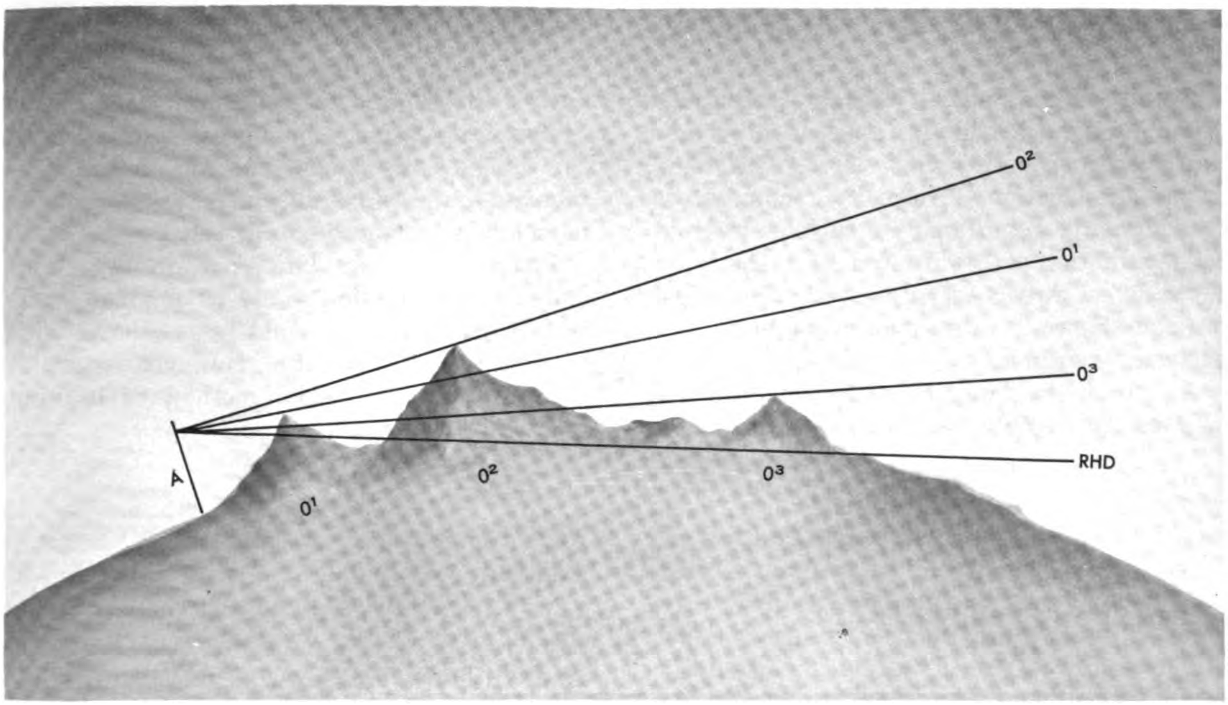


Figure 2–12. *Radar Shadows*

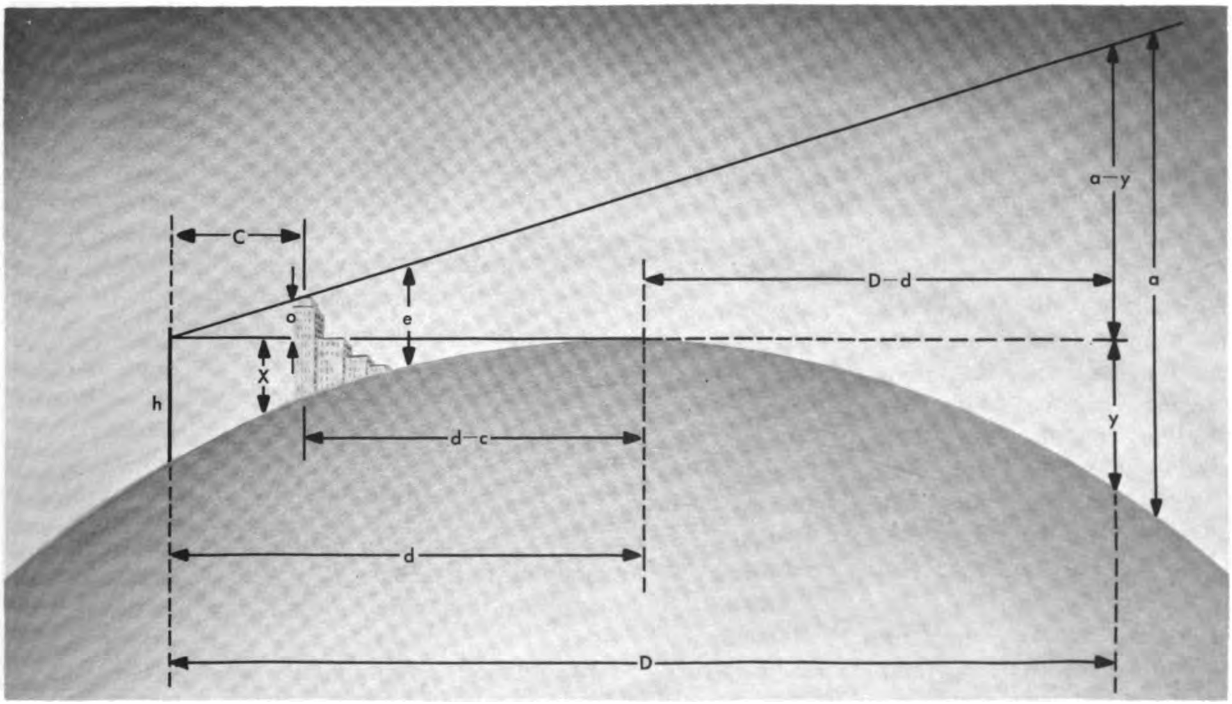


Figure 2–13. *Computing the Radar Detection Distance*

the phenomenon when it occurs, and recognize the conditions that cause it. These include various kinds of meteorological conditions.

RANGE VARIATIONS. Weather conditions probably influence radar range to a greater degree than any other single factor considered under propagation. Normally, temperature and humidity conditions are such as to bend radar radiation earthward and allow the radar set to detect targets slightly beyond the optical horizon. However, atmospheric conditions are extremely variable.

At times, the radar beam is bent strongly upward and rapidly dissipated. This weakens echo signals and reduces the effective range of the radar. At other times, the beam is bent downward, and a duct is formed between the earth's surface and the refracting layer of the atmosphere. In such instances, dissipation of the radar energy is slow and echo strength is increased; the range at which targets can be detected is increased enormously.

PREDICTION. Information pertaining to non-standard propagation would be of great value to EW planners if it could be predicted with any degree of certainty. However, there is presently no established method of making reliable predictions.

CHAPTER 3

Introduction to Air Defense

Air defense includes all measures necessary to prevent, interfere with, or reduce the effectiveness of hostile air action. Destroying enemy factories, airfields, and missile installations will reduce the enemy's air capability and indirectly provide protection against air attacks. In this chapter, however, all offensive operations of this type are excluded.

ACTIVE AND PASSIVE DEFENSE

Air defense measures can be classified into two main categories:

- *Active.* The interception, destruction, and neutralization of enemy air attacks are considered active defense measures. Active air defense for the North American continent is the responsibility of the North American Air Defense Command (NORAD).
- *Passive.* The dispersion, evacuation, camouflage, fire-fighting, radio-broadcast control, blackouts, and decontamination are passive defense measures. Civil defense is the responsibility of federal and state agencies. However, the Air Force assists all civil agencies involved in air defense.

Primary Mission of Air Defense

The primary mission of air defense is the protection of vital objectives which are essential to our economy and our ability to conduct warfare.

The air defense system must be able to prevent the enemy's first attack from paralyzing the capacity to retaliate and further deter the enemy from carrying out successful blows against our productive capacity. To accomplish this, elements of the defensive system must be capable of maintaining air superiority within assigned areas.

Requirements for Conducting Air Defense

The requirements for conducting air defense include: (1) advance information on hostile and friendly air activity, (2) a means for identifying aircraft, (3) intercepting weapons, (4) a control and warning system, and (5) a system of air defense bases.

In addition, there is a requirement for long-range intelligence on the enemy's force disposition and his ability to launch an air attack.

Advance information on the disposition of enemy air weapons aids the commander in planning his air defense. Data on the strength, position, course, speed, and altitude of enemy air weapons enable him to decide the type and number of units to commit against an enemy air attack, and allow time to bring defensive forces into action before the enemy can reach his objective. This data is the basis for coordination and control of the air defense team. It must be available at a central location if the active air defense forces in an area are to be controlled and coordinated by a single authority.

Information on friendly forces must be known by the commander to plan the preparation for air defense. Data must be instantly available to a central location concerning the readiness of air defense units, including the location and status of antiaircraft weapons, the number of aircraft available for combat, and the location of these aircraft. If they are in the air, how much longer can they stay airborne? If on the ground, how ready are they for combat, or how long will it take to reach the proper altitude to intercept the hostile? What type of weather will the friendly forces encounter?

The answers to these questions are necessary for effective interception.

Closely allied to the need for information on hostile and friendly air activity is the requirement for identifying aircraft as either friendly or hostile. An identification process should be instantaneous and positive.

The task of identifying domestic aircraft is extremely difficult and is a serious problem in the present air defense system. Until a satisfactory identification device or system is developed, it will be necessary to acquire, analyze, and correlate a mass of flight-plan and position-report data. Civil air traffic organizations can assist air defense forces in identification.

Once the commander has evaluated the information on friendly and hostile air forces, he must intercept and destroy all attacking forces. At present, interception and destruction are accomplished with interceptor aircraft armed with air-to-air weapons and antiaircraft weapons including guided missiles. Emphasis is shifting to the guided missile for all air defense problems.

Coordination is important between air units (interceptors) and ground units (antiaircraft/missile). Defending aircraft must be kept out of the zones of antiaircraft fire. Antiaircraft units must have some means of positive identification to prevent destruction of friendly interceptors. Also, the position, altitude, course, and speed of noncombat military aircraft must also be continuously available to assure effective air defense operations and preclude unnecessary losses. All agencies responsible for air traffic control must cooperate with air defense forces in carrying out this function.

The locations of air defense interceptor units and radar stations are influenced by the location of defended objectives. To position interceptors properly, it may be necessary to build additional air bases, develop civilian fields, or use airfields jointly with civil aircraft.

For air defense to function properly, there must be a coordinated effort within the air defense team. The SAGE (semiautomatic ground environment) system collects, evaluates, distributes, and displays information on the movement of all air traffic in the area of responsibility. Radar and communications systems are used to gather and distribute the information.

In an air defense system, the main function of ground radar is to collect data for long-range warning, missile guidance, fire control, and intercept control.

Responsibility for Air Defense

The service that has the greatest air defense capability in a given area is assigned the primary responsibility for air defense. Normally, this is the Air Force; however, other services may be assigned air defense responsibility in areas where they have the greater capability.

The organization responsible for air defense would:

1. Prepare the air defense plan.
2. Coordinate with services and with other units having air defense capabilities with civil agencies.
3. Establish an integrated ACW system.
4. Plan training programs in cooperation with all participating air defense forces.

NORAD

Air defense of the North American continent is the responsibility of NORAD, a joint U. S.-Canadian organization. This organization was established in 1957. NORAD has the following component commands assigned:

- USAF—Air Defense Command—responsible for the interception of enemy air objects with its interceptors and surface-to-air missiles.
- U. S. Army—USARDCOM—provides missile defense of prime areas, bases, and cities.
- U. S. Navy—NAVFORCONAD—provides early warning from its available radar and interceptor forces.
- Canada—RCAF ADC—provides air defense forces including interceptors and ACW units.

PLANNING PRINCIPLES

Generally, air defense planners must determine what specific target areas will be defended and how to provide the best possible defense system for them.

Basic planning principles would include but not be limited to the following items:

1. Defense of Selected Objective. An impartial evaluation must be made of the most critical target areas that must be safeguarded with present capabilities.
2. Comprehensive Defense. Air defense must be established regardless of the direction or altitude that the aggressor may choose.
3. Defense in Depth. It must be possible to subject and keep the aggressor under constant attack.
4. Concentration of Force. The defense must be able to bring an overwhelming amount of fire-power to bear on the aggressor in the shortest possible time.
5. Defense in Being. The defense must be adequate at all times. The destructiveness of new weapons and their high speed of delivery make it imperative that air defense be available prior to attack.
6. Progressive and Flexible Defense. The defense must be able to modify, alter, or reorganize with the changing situation, and must also be able to incorporate all the latest technical developments within existing facilities.

Radar Requirements

One of the considerations in the deployment of radars and associated equipment is to determine whether the radars are to be used for close control or strictly for surveillance. This is important, since the requirements differ in each case.

Close-control radar should have:

- Positive tracking.
- Tracking capability in all azimuths.
- Tracking capability at all altitudes of interest.
- A high degree of overlap coverage.
- A high probability of detection within the coverage area.

Surveillance radar should have:

- Long-range detection.
- Overlap coverage.
- A tracking capability.

Deployment of Radars

The minimum extent of radar coverage required can generally be determined by the solution of the basic intercept problem. The solution to this problem will give the general area for the deployment of the equipment; however, the exact location will be determined by utilizing radar siting procedures.

The first step in the solution of this problem is to establish a point in space where the interceptor, or missile, must engage the target.

The second step is determining the location of the minimum detection line. This line represents the minimum distance at which the target must be detected if the defense weapon is to make contact at the established engagement point.

Often, the interceptor bases are not within the target engagement area; therefore, the time the defense weapon requires to reach its target will vary with each individual approach.

Interceptor Deployment

Generally, interceptors should be in the vicinity of the defense area for two reasons:

1. To attack with minimum time loss in any direction the enemy may choose.
2. To increase available combat time if target speeds increase and stand-off weapons such as long-range air-to-ground missiles are developed.

ADA Deployment

The deployment of the air defense artillery (ADA) is dependent on the following factors:

- Target type and location.
- The capability of the enemy air weapon (speed, altitude, and maneuverability).
- Range/speed of AA weapons.
- Overlapping coverage.
- Numbers of guns and/or missiles available.
- Rate of fire.
- Most probable route enemy will approach.

AIR DEFENSE READINESS AND WARNING

Intelligence and early warning information will determine the condition of air defense preparedness and warning. For each condition of air defense preparedness, the air defense system takes predetermined defensive measures. These conditions mean either that intelligence data indicates an intent on the part of a foreign nation to attack us, or that the pattern of unknowns has aroused suspicion. It could be that sabotage has been encountered somewhere within the air defense system.

Air Warning Systems

When an attack is very likely, or when it is apparent that hostile forces are enroute to, or over, the North American continent, an air defense warning condition will be put into effect. This will necessitate warning of the imminence of attack to civil and military agencies.

There are two separate air defense warning systems:

1. MILITARY AIR DEFENSE WARNING SYSTEM. Personnel at the NORAD Combat Operations Center (COC) pass the condition of warning to military air defense units which, in turn, forward the warning as appropriate.
2. CIVIL AIR DEFENSE WARNING SYSTEM. Liaison officers of the Federal Civil Defense Administration (FCDA) disseminate the warning to civil air defense warning centers. The responsibility for warning the public rests entirely with civil authorities in the U. S. A.

There are three conditions of warning used for alerting key points:

- YELLOW WARNING means that attack by hostile vehicles is probable. Currently evaluated information from radar sources or from friendly countries indicates that air vehicles, apparently hostile, are enroute to the North American continent. Notice of yellow warning also includes information on the approximate number of vehicles, their position, altitude, and direction. Yellow warnings are announced publicly.
- RED WARNING means that attack by hostile vehicles is imminent. This means that airborne objects have been identified as hostile and are enroute to or over the North American continent. Red warnings are announced publicly.
- WHITE WARNING means that attack by hostile air vehicles is not considered probable or imminent (all clear). It may follow either a yellow warning or a red warning.

Air Defense Exercises

Periodically NORAD implements full air defense exercises to test the air defense capabilities under actual saturation conditions.

The air defense exercises conducted by NORAD provide dual training and testing. The aircrews attempting to penetrate the defensive net are provided an opportunity to employ EW equipment and develop combat techniques. At the same time, the air defense system is forced to operate under actual war conditions and apply ECCM as much as possible.

These exercises emphasize the problems confronting the EW officer when he penetrates modern air defense systems that are equipped with fixed radars (ECCM) and automatic data handling processes, or when he effectively uses such systems to resist penetrations using ECM. The planning and flying of missions against such systems require a knowledge of their functions, capabilities, and limitations.

INTRODUCTION TO THE SAGE SYSTEM

The SAGE system is that portion of the air defense system of the continental United States that provides the means for the semiautomatic processing of data and of weapons control. The SAGE system consists of the following:

1. Those facilities required to process and transmit air surveillance data from existing and planned data-gathering sources to direction centers.
2. Direction centers, where electronic computers process, evaluate, and display air surveillance data. The computer develops air situation displays at the sector level from which threat evaluation, weapons assignment, and appropriate weapons guidance orders are generated.
3. Those facilities required to transmit situation data from direction centers to the combat center.
4. Combat center, where electronic computers process, evaluate, and display situation data from the direction centers. The computer

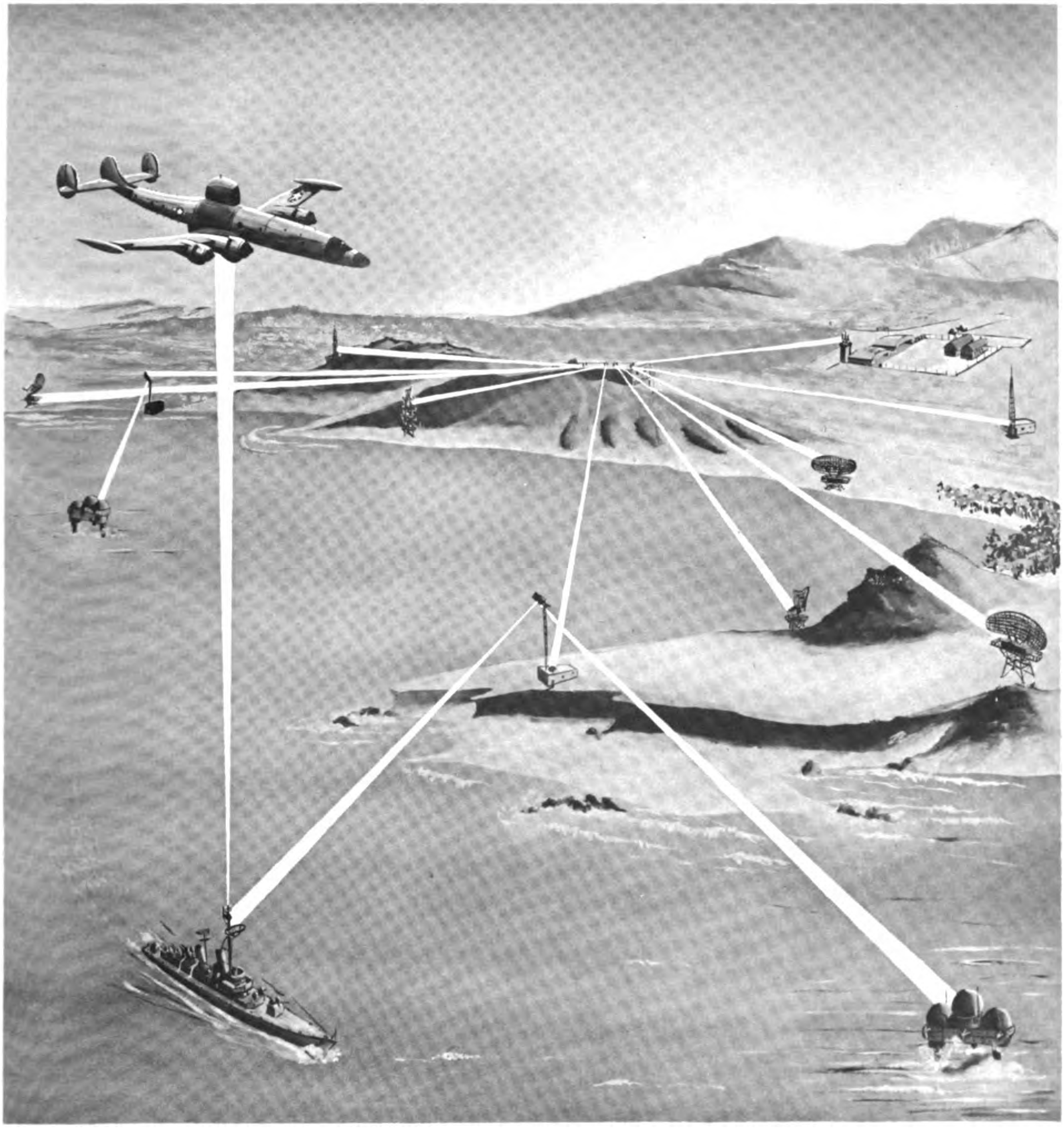


Figure 3–1. *SAGE Direction Center*

develops air situation displays from which the utilization of weapon resources can be monitored and directed.

Data flow is shown in figure 3–1.

The prime concern of air defense is the protection of retaliatory forces, population, natural resources, and industrial potential during an initial or sustained attack by hostile forces. Adequate surveillance and warning time must be available to provide maximum effectiveness and flexibility of mass weapon employment within the combat zone.

To achieve this effectiveness, an air defense system must have facilities for processing and transmitting air-surveillance data from radar outposts and other data-gathering sources, and must be capable of rapidly summarizing and clarifying that data to present a clear and concise picture for action. The greatest problem in air defense, therefore, is reduction of the time required to transmit and process all requisite data. An overall detailed tactical plan for meeting an aerial attack cannot be formed until essential information is available from each element of the air defense system.

CHAPTER 4

Electronic Reconnaissance

The development of air and space power in recent years has vastly increased the need for electronic intelligence. General H. H. Arnold, in his *Third Report of the Commanding General of the Air Forces to the Secretary of War*, pointed out future requirements for superior intelligence on a global scale:

"Strategic air warfare can be neither soundly planned nor efficiently executed without a continuous flow of detailed information.

"There is a great need for a permanent national organization which not only deals with broad questions of policy, but also collects, evaluates, and disseminates a continuous stream of intelligence data. In addition, we must have a competent and active air intelligence organization within the Air Force working with such national organization in times of peace and war.

"Only through specialized channels can we keep a constant check on the technological developments of potential enemies. We must in the future know in detail all conditions and be familiar with all facilities that may affect possible military operations.

"The targets of the future may be very large or extremely small—such as sites for launching guided missiles—requiring exact intelligence information as well as bombing accuracy to destroy them."

The statement made by the late General Arnold still rings true today. The present world situation indicates this must be a continuing requirement.

Electronic reconnaissance is one of the vital specialized channels that the USAF uses to ascertain the technological developments of potential enemies. It is a part of the intelligence requirement necessary to resolve high level military, political, and economic decisions. Information collection must keep pace with foreign technical developments so that American equipment may be designed for maximum effectiveness.

Former President Eisenhower aptly stated the case when he said, "We would be negligent if we failed to gather vital intelligence information."

THE RECONNAISSANCE MISSION

Reconnaissance patrols use specially equipped aircraft that are frequently called ferrets. Electronic reconnaissance officers have been identified by various names such as "ravens," "crows," "ferret operators," and other titles, but this manual will identify them simply as EW officers.

Through the use of reconnaissance equipment, the EW officer can intercept, locate, and record the emissions of electronic equipment. Some preliminary identification is possible by the operator, but electronic intelligence (ELINT) requirements demand permanent recordings for detailed analysis. Thus, ELINT provides the data necessary for design of ECM or ECCM equipment necessary to neutralize hostile electronic controlled weapon systems.

The Purpose of Reconnaissance

The basic need for electronic reconnaissance is to increase the effectiveness of penetration techniques and provide periodic estimates of enemy intent and sensitivity. Not all of the data is collected by electronic reconnaissance, but it often provides the catalyst that promotes collection by collateral agencies.

Aerial reconnaissance is divided into two phases, tactical and strategic. The distinction is based on the use of the resulting information. Tactical reconnaissance offers immediate support for striking forces by providing information concerning day-to-day warfare. Strategic reconnaissance seeks information about targets in an overall system; it must include all features of terrain, installations, movements, etc. This information allows intelligence experts to analyze, evaluate, and select targets for destruction in patterns which are designed for optimum results.

The Electronic Reconnaissance Cycle

Reconnaissance has only one end product—intelligence which is current, complete, and valid. Since time is the greatest degrader of intelligence, the reconnaissance cycle must keep a level of activity commensurate with the intelligence requirement. This provides commanders with the necessary facts to formulate policy and make decisions. Reconnaissance must follow a logical sequence to obtain the best intelligence and fulfill the requirements for which it was designed. The reconnaissance cycle generally follows the pattern and sequence outlined below:

1. Target development—to determine the most valuable targets.
2. Prestrike—to confirm existing intelligence and discover new changes. The information obtained will normally affect tactics employed.
3. Route reconnaissance—to furnish weather and other significant information.
4. Poststrike reconnaissance—to assess damage and the need for further destruction of the target. Present concepts of war may not make this type of reconnaissance a necessity.
5. Surveillance—the never-ending process to determine disposition of forces and equipment. This can be tactical or strategic in concept, depending on the progress of battle or future needs for the intelligence information.

Types of Electronic Reconnaissance Missions

The types or code names for electronic reconnaissance missions vary by command. However, the basic mission type can be resolved to variations of general or specific band, area, or type emitter search. The intent may be confirmation or reconfirmation of an order of battle, or search for new signal sources. The route profiles necessary to accomplish the mission can be categorized as peripheral (within or without the detection range of the electronic environment) or penetration type (which seeks or homes on specific emitters for tactical purposes).

Development of the Plan

The commander's estimate may be written or verbal; it is defined as the weighing of all factors to determine the best approach to solve the problem. In the development of an electronic reconnaissance mission, for example, the following factors must be taken into consideration:

- The urgency of the intelligence requirement.
- The enemy defense capability.
- The sensitivity of the area involved.
- The capability and limitations of friendly forces to obtain this requirement.

Electronic reconnaissance operations require detailed planning before the actual accomplishment of the mission. After formulation and justification of the intelligence requirement, the staff specialists are consulted for the necessary information to successfully accomplish the mission. Such factors as the selection of the vehicle, route preparation, operational tactics and procedures, logistics plan, and theater coordination are carefully designed before the operations order is issued. Lower echelon commanders will then issue necessary instructions, select aircraft, and assign crews to execute the sortie.

Briefings and debriefings are generally accomplished at the theatre of operations by unit or intelligence personnel. Data collected is then evaluated for exploitation in war planning.

The EW officer has the final responsibility for the success of a reconnaissance mission. He must understand what is required in the way of intelligence and must possess the necessary technical and professional skill to accomplish this.

In the final analysis, the tremendous effort in planning, execution, and evaluation of data from the reconnaissance mission is nothing more than placing the EW officer in the target environment for the necessary period of time to satisfy the intelligence requirement.

Flying the Electronic Reconnaissance Mission

Quality collection of raw intelligence is the ultimate goal of any electronic reconnaissance mission. This can only be attained through a professional approach to the collection problems. Pretarget study, premission planning, preflighting of equipment, and airborne crew coordination ultimately affect the quality of collected data.

The EW officer is individually responsible for the quality level of collection on manual and semiautomatic reconnaissance systems. Selection and rejection of intercepts occur at this point. This action requires a thorough understanding of special design features and operating techniques of the hostile environment which affect the probability of intercept. The EW officer must therefore be prepared to record the required data immediately upon intercept of a signal of interest.

Reporting Procedures

The information which the EW officer collects on a reconnaissance mission is of little value unless it can be processed into useful intelligence. This detailed information cannot be memorized, so written and recorded flight data are prepared in a designated format and forwarded to intelligence processing organizations. The intercepted raw data is converted into electronic intelligence (ELINT) information.

ELINT report formats, types, and report due times will vary with the controlling command requirements. As with all intelligence, timeliness and accuracy are essential. Field units must receive immediate notification of significant electronic environmental developments, so that proper actions can be taken in the event of hostilities. For this reason, electrically transmitted mission reports are becoming predominant. A typical mission reporting cycle may consist of:

1. An inflight report submitted by the aircrew. Intercepts to be reported in this manner will generally be determined in premission briefings.
2. A preliminary report by an ELINT processing unit on new and unusual intercepts.
3. A final report and detailed analysis of all mission intercepts.

EQUIPMENT

The rapid buildup and complexity of the modern day electronic environment has heavily tasked electronic reconnaissance equipment. The inherent weaknesses of limited detection and the laborious data reduction peculiar to manual systems has dictated a new trend toward automation in both collection and analysis.

Regardless of the type of system employed —whether manual, semiautomatic, or automatic—the theory of manned aircraft collection remains unchanged. Only the methods of recording data and techniques in analysis have been altered.

Manual Electronic Reconnaissance Systems

Essentially, a manually operated electronic reconnaissance system includes these basic subsystems: intercept receiver, pulse analyzer, D/F unit, and recording system.

RECEIVER. The receiver is used to intercept victim emissions. As such, it is the most important single subsystem of the equipment configurations. Although the carrier frequency is the basic information derived from the receiver, it may also obtain simultaneous indications of the type modulation, scan type and rate, pulse recurrence frequency, relative signal strength, relative antenna beam width and lobe characteristics, and the frequency range and agility of the transmitter.

PULSE ANALYZER. A portion of the detected signal is routed from the receiver to the pulse analyzer. Specialized circuits within this equipment separate and display the pulsed characteristics of the emissions. Basic information obtained from this equipment includes the pulse recurrence frequency, pulse shape, and pulse width.

D/F UNIT. The D/F unit uses a portion of the receiver output to visually display relative bearings from the aircraft to the transmitter. Polarity of the signal can also be determined through specialized antenna circuitry. Emitter location is thus determined through computation of a series of relative bearings versus aircraft heading. The formula is:

$$TB = TH + RB$$

Where TB = true bearing
TH = true heading
RB = relative bearing obtained from DF unit

RECORDERS. Recordings are normally made of all intercepts so that detailed analysis can be made by ELINT processing units to ascertain parameters. Typical manual systems include the operator's written logs, audio and video magnetic recordings, and photography.

Semiautomatic and Automatic Electronic Reconnaissance Systems

Semiautomatic and automatic systems have generally integrated the manual subsystems into either one or two packaged units. Recording is accomplished through combinations of audio and video magnetic techniques and photography. Data reduction time varies from a comparatively lengthy period for semiautomatic systems to extremely rapid analysis for automatic systems. Both use computers.

Spurious Responses

Spurious responses are no longer considered a major problem area with the modern day receiver. The problem has been generally resolved through attenuation circuitry and electromagnetic shielding. However, certain manual reconnaissance receivers may occasionally present a spurious response and the EW officer should be prepared to recognize and reject such signals.

CHAPTER 5

Active Electronic Countermeasures

Active ECM is defined as all measures taken to nullify the efficient operation of enemy electronic systems. The measures can be physical or electromagnetic in nature. Destruction and evasion of enemy electronic systems are examples of physical measures. Jamming and chaff are examples of electromagnetic measures.

The definition for active ECM by electromagnetic means is restricted to the radiation or reradiation of electromagnetic energy to adversely affect the operation of electronic systems. Hence, there are two broad categories of active ECM devices: those that radiate and those that reradiate.

Further differentiation between these two categories is based upon the fact that radiating devices use electronic means to create jamming energy, whereas the reradiating devices are mechanical and merely reflect electromagnetic energy.

A method that is not included in the above definition is absorption. Absorption is the process whereby some or all of the energy of electromagnetic radiation is transferred to the body on which it is incident. Since it is a material that absorbs radiated electromagnetic energy, its action is opposite in nature to mechanical reradiating devices.

DESTRUCTION AND EVASION TECHNIQUES

Destruction and evasion of electronic systems is the most positive application of ECM when it can be accomplished.

Destruction, or radar-busting, requires information on radar location and operating parameters. The stringent requirements for selective radar-busting has limited this ECM technique. However, further effort is being devoted towards developing effective radar-busting systems.

Evasion requires the air weapon to overfly, underfly, or take advantage of shadow areas to neutralize the electronic defensive system. When this is possible, it is an effective, positive countermeasure.

The employment of sophisticated high performance radars and radar overlap make the technique of evasion more difficult to perform. The use of low level tactics would probably be effective today. However, the defensive systems have been alerted to this possibility and are probably correcting this deficiency. In the immediate future, the use of low level tactics without ECM will probably produce unacceptable attrition.

Another possibility of evasion exploits the irregular antenna patterns of search radars. Here, too, evasion is difficult because the determination of the lobe pattern of a specific radar is an exacting job. Furthermore, routing bombers between these lobes is even more exacting.

Another source of evasion cover is cloud formations. The performance of microwave radars is often degraded by cloud coverage which has a high moisture content. This must be considered a bonus benefit, since no reliance can be placed on the right type of cloud coverage for normal operations.

High-altitude nuclear blasts could also be a source of evasion cover. It has been noted that such high-altitude bursts produce considerable interference to some frequencies. This is sometimes called the Argus effect.

Evasion can be carried a step further by the use of maneuvers. Evasive maneuvers include the tactics of using decoys to simulate bombers, diversionary raids, and roll-back technique. This is considered a very effective countermeasure, because it tends to degrade or stay beyond the defense capabilities.

Destruction and evasion have distinct applications as ECM techniques. But there are too many variables which cannot be controlled that tend to limit the reliability of these countermeasures. Therefore, the emphasis is on countermeasures that give greater control of these variables that make the defense possibilities less effective. However, the relative advantages of destruction and evasion techniques should not be neglected in electronic warfare operations.

MECHANICAL OR RERADIATING DEVICES

One of the first, and still effective, ECM devices is chaff. Chaff, rope, and corner reflectors are mechanical or reradiating devices. These are shaped, resonant pieces of material used to reflect electromagnetic energy and thus create radar echoes for ECM purposes.

Chaff

Chaff operates against radar in three ways: by creating targets, by concealing targets, and by causing confusion and delay.

More specifically, chaff works on the principle that the target might penetrate the defense systems undetected or unidentified when the radar is bombarded by a multiude of misleading signals. Furthermore, even though the radar may locate the target, the addition of chaff induces errors in tracking functions and may disrupt automatic tracking entirely. Chaff tends to saturate the capability of the radar and creates doubts, confusion, and delay among the victim radar operators.

Properly used, chaff can reduce losses from enemy interception and fire control weapons.

The basic principles of the use of chaff may be summarized as follows. Foil, usually aluminum, is cut into thin strips or dipoles, the length of which determines the resonant frequency. Chaff is made to respond to a wide band of frequencies by packaging several different lengths of dipoles in the same bundle. Chaff is slip-coated to prevent "bird-nesting" and strip-coated to give it random polarization.

The echo created by resonant dipoles is much greater than that created by objects whose resonant frequency does not correspond to the impinging frequency. To simulate the radar return of a large but essentially nonresonant object such as an aircraft, only a relatively small volume of chaff dipoles is required. Each unit of chaff contains enough dipoles to give a radar response as large as an aircraft echo.

The overall success of the use of chaff in World War II was difficult to evaluate while the war was in progress. At the close of the war, an investigation was made to determine the effectiveness of the countermeasures program.

The Germans admitted that the countermeasures program was extremely effective. The effectiveness of radar controlled antiaircraft fire was reduced as much as 75 percent due to countermeasures. A measure of the success of the chaff program was the fact that approximately 50 percent of the German electronic scientists devoted their time to development of antichaff modifications.

The weight and volume of the World War II chaff series were excessive in terms of modern-day requirements. The six standard chaff units had a gross weight of more than six pounds and a total volume of 253 cubic inches. The high percentage of bird-nesting of the dipoles and their failure to meet polarization requirements materially reduced the effectiveness of the units.

A series of experiments was undertaken to produce a foil which could be effectively cut to narrower widths and thinner gauge, and which could be dispensed with a minimum of bird-nesting. This phase of the research program resulted in the development of a new type lacquer coating for the foil, identified as "slip-coating."

This slip-coating, when applied to one surface of an aluminum foil sheet, produces a hard, smooth film with a minimum amount of surface friction. It facilitates the cutting of narrow strips of foil without edge welding, and reduces the bird-nesting factor by 50 percent. Using slip-coated foil, it is possible to reduce the thickness of the dipoles to 0.00045 inch and the width to 0.036 inch.

A newer slip coating is a silicone base agent that is applied to both sides of the dipoles. This coating reduces the bird-nesting factor and permits the use of dipoles cut to a width of 0.008 inches.

The polarization requirements for dipoles less than 4 inches in length presented another major problem. Dipoles of less than 4 inches in length tend to fall horizontally, hence are at right angles to polarization of various radar antennas. Improper polarization of the chaff dipoles results in the return of little or no power, and affords little protection.

The solution of this problem is also found in lacquer coating. A weighted lacquer is applied to the surface of the aluminum foil in such a manner that only a portion of the finished dipole is coated. This application of lacquer is called "strip-coating." By varying the amount of strip-coating on the dipole length, variations in the dipoles center of gravity is obtained. Thus, when the dipoles are dispensed, a random orientation of polarization is produced.

As a result of these developments, a new chaff series was designed. Development in packaging and dispensing made possible the automatic dispensing of a large payload of chaff under any conditions.

The modernization of World War II chaff was accomplished, but many other problems remained. Too many different types of chaff were still required. Since the problems of production, supply, and tactical planning are complicated by having many types, a major effort has been initiated to reduce the number of different units required to cover the entire RF spectrum.

Rope

The chaff standardization program could not be made effective without comparable improvements in the characteristics of "rope." Rope is made of long strips of reflective material and is used for frequencies below 600 mc.

In considering the frequency range of 10 to 600 megacycles, the design of a new unit presented several difficulties. It is extremely difficult to forecast or measure the response of rope because of the deviating lengths of foil unwound from the roll and the configurations of the unwound foil ribbons. Each of these is a factor which is difficult to measure with any degree of accuracy, and, in effect, varies with the prevailing weather and flight conditions at the time of the drop.

It became necessary to undertake a most extensive series of laboratory experiments and field tests in order to increase our knowledge of the functioning of rope. Both the British and Canadian governments cooperated with the USAF in this project.

A series of design changes grew out of this effort, ending in an entirely new concept of reflector known as level-spooled rope. The length was increased without a corresponding weight increase by cutting rope to different dimensions. In previous designs, the rope unwound from its outside diameter toward the core. In the new design (level spooled), the core is removed and the foil ribbon is unwound from its center at a rapid rate.

The level-spooled rope unit, together with the broad bandwidth dipole units covering the frequency range of 600 to 11,000 megacycles, constitute the new improved chaff developments. In addition to reducing the number of units required to cover the frequency spectrum, the new series reduces the weight of the units by 56 percent and the volume by 70 percent when compared to World War II chaff.

The research program is being continued. Additional emphasis is being given to using other materials rather than aluminum foil. Mylar, impregnated with metallic material, has been most promising. In addition, single units of chaff weighing approximately a pound, with a volume of less than 30 cubic inches, have been developed. This single unit is capable of returning an echo as large as the B–52 to all radars operating between 10 and 11,000 megacycles.

Two new tapeless chaff units have become Air Force standard. These are 1 inch x 3 inches x 5 inches in size, weigh approximately 0.5 pound, and comprise a low frequency and a high frequency unit. New dispensers are required for these units.

Why do chaff and rope continue to be effective countermeasures even with new high-power, frequency-diversified radars? The answer is apparent when you use the terms high-power and wide-frequency bands. Since chaff is reflective in nature and has been given broad bandwidth capabilities in single units, it will necessarily reflect the radar signal with comparable strength and frequency. Power, frequency-diversity, and rapid-frequency shifting cannot evade the effectiveness of reradiating materials.

Chaff is not infallible. Its greatest weakness is its lack of velocity. Many of the new radar ECCM fixes tend to exploit this weakness. On the other hand, chaff is not inflexible. It has been given velocities, either real or apparent, by rockets and delayed opening devices.

Another development is quick-blooming or rapid-opening chaff. This was developed to assure that the chaff would blossom within the same resolution cell of a radar as the illuminated aircraft.

Rate of fall for chaff was extremely important when mass-screening chaff tactics were the order of the day. With the emphasis on producing multiple returns and breaking the lock of the automatic tracking system, random burst technique is more valuable. Therefore, there is less concern with the rate of fall, and more on target production. However, it is felt that some discussion on the rate of fall and dispersion properties of chaff is necessary.

The effective rate of fall of chaff is normally figured at 300 feet per minute. Wind, temperature and moisture content of the atmosphere, altitude and speed of the dispensing vehicle, plus the type, size, and weight of the chaff being used are all variable factors that affect the rate of fall and dispersion characteristics of chaff. No attempt is made to determine the actual rate of fall for chaff under each dispensing situation.

When chaff is dropped from above 10,000 feet, echoes may be returned for as long as thirty minutes. On the other hand, chaff dropped from very high altitudes will tend to dispense so widely that it often loses all target producing capability before reaching the ground. As a general rule, chaff cannot be depended upon to provide false targets and effective countermeasures for more than 30 minutes after dispensing.

Corner Reflectors

Corner reflectors are specialized reradiating devices. A corner reflector is a device consisting of three mutually perpendicular, intersecting metallic planes which form eight corners, thereby providing an effective reflective surface to electronic energy which strikes it from any direction. The outstanding advantage of the corner reflector over other reflectors is its great reflectivity, regardless of its orientation to the radar from which the energy originated.

Corner reflectors have their greatest application in radar camouflage. By this technique, replicas of real targets are built some distance away from the true target.

The most promising airborne application of corner reflectors is their use on drones and decoys. This technique allows mass-produced, expendable vehicles to appear as operational targets on radar scopes.

Radar Absorbing Materials

Radar absorbing materials (RAM) are materials applied to vehicles for the purpose of absorbing or attenuating radar reflective energy. RAM is used to prevent or decrease detection probability, rather than to create targets.

It must be pointed out that complete absorption is improbable; however, even attenuating the power of the transmitting radar signal by 12 DB would have the effect of cutting the radar range in half. Therefore, a vehicle coated with RAM would have its reflective cross-section effectively reduced, and would require less powerful jamming to screen itself.

The ideal absorption material for airborne use must be thin and light to avoid degradation of flight characteristics; it must be rugged enough to withstand high-speed environments; and it must have broadband characteristics to assure absorption over wide frequency ranges.

Most of the absorbers under consideration are based on transmission line theory. Other more promising techniques which are classified are currently being investigated. Satisfactory application and binding of the material to the vehicle is a very difficult problem at the present time.

ELECTRONIC JAMMING

Electronic jamming is defined as the generation and radiation of electromagnetic energy for ECM purposes. Of the EW techniques, electronic jamming is the most widely used and the most effective on a large scale. It offers the greatest control and flexibility and forces a victim radar to use countermeasures to remain effective.

With unlimited resources and determination, any open radiation system can be jammed. Open radiation is defined as the radiating of energy through free space as opposed to its transmission through wire or other transmission line devices.

For every good jammer developed, the enemy is forced to revamp or replace huge segments of his electronic systems. Most of the radar fixes are designed to evade jamming degradation. But for every radar fix developed there is an overall sacrifice of operational capability. The ever-increasing complexity of modern fixed radars is cited as an example.

Even though some ECM devices never find actual application, they do tend to tie up tremendous resources. In effect, electronic warfare can be considered an economic weapon, since it requires tremendous outlays of money and technological skill to keep electronic systems operational in an ECM environment.

Jamming is effective because of certain inherent radar characteristics. Radar receivers must be extremely sensitive to receive the small amounts of energy reflected from targets. It is therefore relatively easy for a jammer to generate power which is greater than the reflected skin-paint energy of the target.

The purpose of electronic jamming is to keep the radar from locating and tracking targets of interest. This is accomplished by transmitting energy to reduce the radar's ability to detect targets, or by deceiving it with false information. Sufficient delay in target acquisition limits this capability and reduces attrition of the attacking force.

Electronic jamming is divided into two general categories, *saturation* and *confusion/deception.* Saturation depends on returning more power to the radar receiver than it receives from the reflected echo. The introduction of false or delayed signals into enemy receiving equipment to confuse normal intelligence is labeled confusion/deception.

SATURATION JAMMING

The requirements for saturation jamming vary with the system to be countered but must include three general capabilities, which are:

- The jamming transmission must be continuous.
- The jamming power must be great enough to do the job.
- The jammer should be able to match the victim signal in bandwidth, frequency range, and frequency shifting capability.

Continuous Jamming Signals

Electronic control of modern weapons can be maintained, even though the controlling intelligence is applied intermittently. Thus, an intermittent jamming signal probably will not seriously degrade the guidance information.

The intermittent jamming signal will usually allow enough intelligence to get through to operate the weapon successfully. A continuous jamming signal of sufficient power will prevent intelligence from seeping through at intervals and thus will degrade electronic control capabilities.

Power Requirements

Power requirements and radiation capacity are the primary factors in providing effective electronic jamming. Given enough power, any electronic system can be countered.

POWER DISTRIBUTION. The power per megacycle radiated by a jammer is inversely proportional to the bandwidth of the jammer. As you can see in the graph in figure 5–1, a jammer providing a signal one megacycle in bandwidth radiates ten times more power per

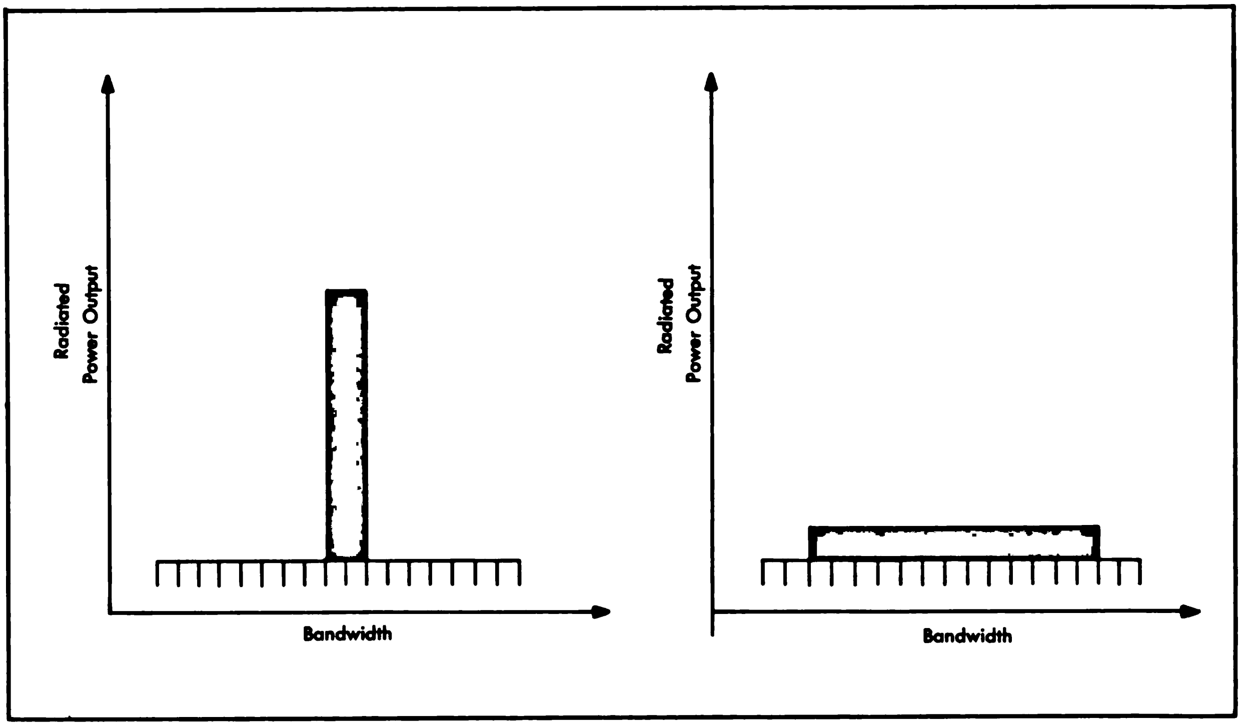


Figure 5–1. *Power Varies Inversely with Bandwidth*

megacycle than if its bandwidth covered ten megacycles.

In other words, the total available power from a jammer is distributed throughout its bandwidth. As the bandwidth is broadened, the watts per megacycle of bandwidth is reduced.

It is readily apparent that a wide-band transmitted with insufficient or limited power has many disadvantages. Interference may be introduced in several electronic systems that are closely spaced in frequency, yet the power per megacycle may be too low in all of them for effective jamming. And, in some cases, ineffective jamming is more dangerous than no jamming, because weak jamming has a tendency to spotlight the offender.

JAMMING TO SIGNAL RATIO. The jamming signal is always in competition with the intelligence signal, so that the ratio of the jamming power to reflected signal power must be high if effective jamming is to be accomplished.

In jamming radars, this jam-to-signal power (J/S) ratio depends on a number of factors. These include the power of the jamming transmitter, the power of the radar transmitter, the distance between the jammer and the radar, the radiation patterns of the antennas involved, and the effective cross-sectional reflection area of the target being concealed by the jamming signal.

It is obvious that the effectiveness of the jamming is increased as the jamming power is increased. Likewise, if all other factors remain constant, the effectiveness of the jamming is decreased as the power of the radar is increased.

Ground-based radars can afford to concentrate on power, whereas airborne jamming equipment is restricted in power due to weight and size limitations. For this reason, jammer design is switching from the brute-force technique to more sophisticated methods.

MINIMUM SELF-SCREENING RANGE. Distances separating the equipment in a jamming situation must also be considered. Signal power is inversely proportional to the square of the distance in one way transmissions. When the signal must travel to a target and be reflected back, the signal power is inversely proportional to the fourth power of the distance between the radar and the target.

Since jamming signals are used in one-way transmission, they enjoy a distinct power advantage over radar reflected energy at most ranges.

However, when a jamming aircraft approaches a radar site, its jamming power increases by the square of the distance, whereas the echo power of the radar increases by the fourth power. Therefore, at some point, the echo power will become stronger than the jamming power and the victim radar will be able to read through the jamming.

The distance from the radar to where J/S ratio is unity is known as the minimum jamming range or self-screening range of the radar. The relationship of the jamming to signal power ratio is more clearly illustrated on the graph in figure 5–2.

Note that at point C of the graph, the jammer power received at the radar site is greater than the echo from the aircraft carrying the jammer. As the distance decreases between the jamming aircraft and the victim radar, the situation changes. Thus, at point B the crossover point is reached, and the echo becomes more powerful than the jamming. At this point the aircraft is no longer protected.

Now consider the other factors involved. If you increase the power of the jammer in the aircraft and let all other factors remain unchanged, point B will be displaced to the left and the minimum self-screening range will be decreased. If the power of the radar transmitter is increased, the echo from the jammer aircraft will be increased and point P will be displaced to the right. In addition, the jamming power and echo power at the receiver vary with the directivity or gain of the antennas in use. Conversely, if a larger aircraft (larger radar cross-sectional reflection area) is used and other conditions remain constant, the echo will be greater and point B will be shifted to the right.

Frequency Requirements

The effectiveness of a jammer is greatly increased when its frequency capabilities specifically match those of the enemy signal. The three main points in frequency requirements are bandwidth, modulation, and tuning capabilities.

Bandwidth. The bandwidths of communication receivers are extremely narrow when compared to those of a radar receiver. In most cases the type of signal to be handled determines the receiver's bandwidth.

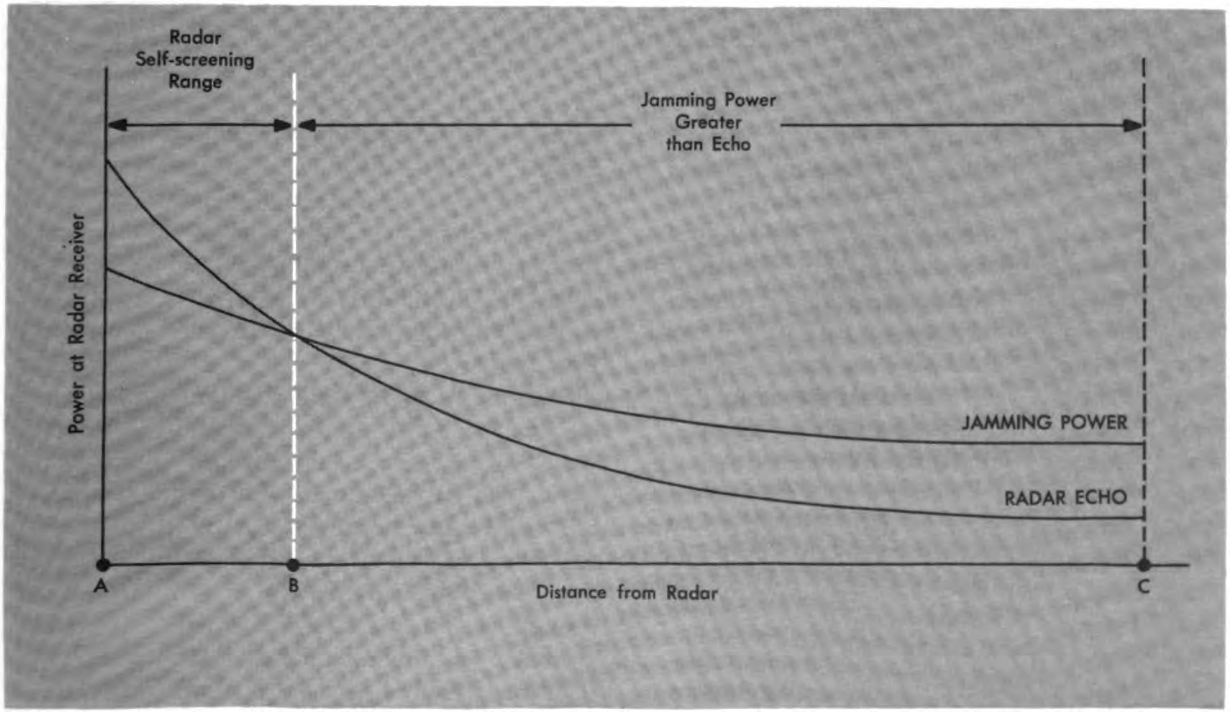


Figure 5–2. *Minimum Self-Screening Range*

Voice transmissions require a wider bandwidth than CW transmission. Pulsed signals, because of the many frequencies which make up a pulse, require a bandwidth of several megacycles, depending on the desired sharpness of the pulse definition.

If a jammer producing a signal with a 30 kc bandwidth is used to counter a radar with a bandwidth of 3 mc, only 0.01 of the radar's bandwidth is interfered with by jamming. Sufficient radar intelligence will therefore continue to be received in spite of the jamming signal. Conversely, if a jammer with a wide bandwidth is used against an enemy signal with an extremely narrow bandwidth, most of the jammer's power is wasted at either side of the receiver's bandpass.

Bandwidth is extremely important in jamming single radars (spot jamming), but requires entirely different emphasis when attempting to jam many radars (barrage jamming) within certain frequency limitations. The ideal spot-jammer bandwidth is one which is only slightly wider than the bandwidth of the receiver against which it is to be used.

MODULATION. Modulation is the variation of a carrier wave in accordance with another signal. This variation constitutes the intelligence which is conveyed from transmitter to receiver. In electronic jamming of radars, it is desirable to transmit a carrier modulated by a masking signal instead of intelligence.

The type of modulation used by a jammer is very important when complete masking of intelligence is desired. If, for example, you listen to a home radio and hear a continuous 1000-cycle note along with the announcer's voice, you find it annoying but still understandable. By paying close attention, you can distinguish the announcer's message. In the same way, if two conversations are carried on simultaneously, you can choose the one you want to hear and ignore the other.

In both of these examples, interference is present, but you can select the intelligence in spite of the interference. This is because the interference is not composed of a frequency spread sufficient to mask the intelligence.

However, in the case of the home radio, when an electrical storm produces continuous static, it is impossible to derive any intelligence from the announcer's voice. If instead of two conversations you have a hundred conversations from which to select only one, you find the task much more difficult.

Interference, in the form of static and multiple conversations is effective because it is made up of a sufficient number of frequencies to mask the intelligence. In actual practice it has been found that noise is an excellent masking signal, because it consists of an infinite number of frequencies.

Noise modulation is used in most ECM transmitters. Other types of modulation have been tried, but as yet none of them have proved as effective as noise. White noise, such as shot and thermal noise, is a random type which has a constant energy per unit bandwidth that is independent of the central frequency of the band. Since the electrical energy of this type of noise is evenly distributed throughout the entire frequency spectrum, it lends itself well to ECM purposes.

Noise jamming has several distinct advantages, including the following:

- Noise has a random characteristic, both in amplitude and instantaneous frequency.
- Noise has a uniform spectrum distribution of energy, except as it may be influenced by circuit elements.
- Noise has no particular recurring frequency, so it cannot be eliminated on the basis of frequency without removing the desired signal. Integration or correlation techniques can remove noise from a repetitive signal.

In practice, considerable amounts of incidental frequency modulation may be present in the noise-modulated signal, causing relatively large amounts of energy to be spread over a considerable band in the vicinity of the carrier frequency. This is advantageous since transmitters having incidental frequency modulation (FM) of the carrier are more effective in jamming receivers close to the nominal carrier frequency than if frequency modulation were not present.

Incidental frequency modulation allows carrier energy to be effective in jamming, even though carrier wave (CW) antijamming devices may be in use. Thus, the best type of jamming signal is one that is amplitude modulated by noise and also has a frequency-modulated component.

TUNING CAPABILITIES. A jammer must be able to tune over a relatively wide frequency band. Enemy electronic systems are seldom operated on one specific frequency.

A typical GCI search radar may operate on any frequency between 2800 and 3100 mc. A jammer designed to counter a set of this type would have to be able to emit any frequency within the same band. The wider the band over which a jammer is capable of being tuned, the more flexible it is in tactical applications.

Another desirable frequency characteristic of a jamming transmitter is its ability to change frequency rapidly to match the frequency changing capability of the set against which it is working. The ideal jammer is one which can shift frequency right along with the victim system.

Techniques of Saturation Jamming

There are four basic saturation jamming techniques: spot, barrage, swept, and automatic sequential jamming. All of these methods have certain advantages and disadvantages. Actual employment of all or any of the techniques is governed by the tactical situation.

SPOT JAMMING. Spot jamming concentrates all of the available energy on a specific signal. It therefore has a high degree of effectiveness on a single signal, since it offers the greatest power per megacycle from a given jammer.

There are several disadvantages to spot jamming. Modern nuclear weapons make it possible to strike targets with a single aircraft. A single aircraft cannot carry enough equipment to spot jam all electronic defensive systems. Therefore, emphasis can only be given to jamming selected defensive weapons guidance systems that offer the greatest threat to the striking aircraft.

Another disadvantage is that spot jamming requires either a trained operator with intercept equipment or automatic set-on receivers. Both the operator and set-on systems require space, weight, and power that could be used for increased jamming power.

A typically manned spot-jamming position consists of an intercept receiver, panoramic indicator, and a series of jamming transmitters. The system as such is not restricted to spot jamming, but attempts to focus the best jamming capability against the systems offering the greatest threat. Spot jamming offers the greatest power per mc, but it also permits easy evasion of the jamming signal by ECCM (e.g., detuning or changing frequencies).

Radar frequency agility makes the technique of *look-thru* a necessity when spot jamming. Look-thru is a procedure which allows the EW officer to receive the victim radar while jamming. This permits him to follow the radar frequency shifts when the radar victim attempts to evade the jamming signal.

Look-thru operates on a time sharing principle; the jammer is shut down momentarily to hear or see the radar signal. If the victim radar signal can no longer be detected during look-thru, then immediate search for another signal should be started.

The jammer should always be maintained in the standby position when not actively jamming a threat. Unnecessary jamming should always be avoided, since it limits the signal interception capability of the spot-jamming defensive system operator, and it increases the range of enemy passive detection sites.

BARRAGE JAMMING. Barrage jamming is the technique of jamming across a wide bandwidth of frequencies. Its advantage is that the jammer needs to know only generalized information about the radars it is attempting to jam.

Barrage jamming is usually effective against all types of radar modulation, provided it has a healthy power advantage over the reflected radar signals. However, barrage jamming tends to waste power, interferes with friendly electronic systems, and is easily detected by passive direction finders.

Radars are designed to operate in certain frequency bands which may be spread out over several hundred megacycles. During the mission, multiple jammers are turned on simultaneously and the entire enemy radar system within the band is subjected to barrage jamming. With sufficient power and proper application, it becomes impossible for the enemy to detune and break out of the jamming barrage.

With narrow bandwidth type jammers, effective barrage jamming is severely handicapped. This means many jammers must be carried to jam various frequency bands. For example, a typical jammer with a 5 mc bandwidth requires 40 separate transmitters to cover a radar band covering only 200 megacycles. Even then, adequate protection cannot be provided for all aircraft unless they mutually support each other.

A weakness of barrage jamming is that it is dependent on accurate prestrike EW reconnaissance. Once a strike is airborne, the pretuning has committed the jammers to certain frequency coverage. Enemy radar threats operating outside these bands will be unmolested.

Still another problem in barrage jamming is that there may be "holes," or unjammed portions in the jamming pattern, because of jammer drift, set failure, or combat losses. To minimize this, sufficient overlap and back-up jammer strength is provided; or else an EW officer, with a number of spot jammers, monitors the band and plugs the holes as they occur.

SWEEP JAMMING. A swept-frequency jammer is one that sweeps a band of frequencies. These jammers can be effective against highly tunable radars. Sweep jamming can be under the control of an EW officer, who searches for a signal as in spot jamming. But most sweep jamming is accomplished on an unattended basis.

AUTOMATIC SEQUENTIAL JAMMING. The automatic sequential jammer has a video receiver which can tune across a frequency band. Any signal received can be jammed automatically for a programmed period with automatic look-thru. After jamming for a programmed period, the system searches for another signal and jams it, following the same sequence.

An entire frequency range can be jammed in this manner.

CONFUSION AND DECEPTION

Confusion- and deception-type jamming depends on introducing false or delayed signals into enemy receiving equipment by electronic means. It is considered a far more imaginative method of jamming than other types. Ideally, it depends on the enemy unknowingly reacting to false information.

Confusion

Confusion depends on creating multiple targets. A multiple target generator returns to the victim radar an indication of many targets when, in reality, there is but one. By penetrating a radar's side lobes, these could be spread out all over the scope, confusing the radar operator and saturating the system.

A jamming signal at some multiple of the radar's pulse repetition frequency (PRF) is another confusion technique. This method creates a series of concentric patterns on the radar scope. A jagged presentation occurs when the PRF of the jamming signal is slightly out of synchronization with the incoming PRF.

For the power expended, this technique is far more effective than saturation jamming.

Deception

Deceptive countermeasures are accomplished by degrading target information and introducing false returns into the victim radar. Deception tools include repeater jammers, transponders, inverse gain, and gate-stealer devices.

A repeater jammer is an EW system for receiving, amplifying, remodulating, and retransmitting radar signals on a nearly instantaneous basis.

A transponder jammer is a tuned or untuned device that repeats the interrogating signal with a time delay.

A range-gate stealer is a device that captures the range gate of a tracking radar and feeds false information on to the radar by delaying the return.

Velocity-gate stealers are devices used against Doppler-tracking radars which develop false Doppler-shift frequencies to prevent accurate tracking.

Angle-track breaker jammers are used against conical-scan type radar systems to prevent accurate tracking by transmitting signals modulated at the scan rate of the radar.

Deception systems are much more complex than brute-force jammers, but they are also more efficient in the use of radiated power. One of the major problems is building these devices into small, reliable packages.

CHAPTER 6

Antennas

Antennas are devices for the conversion of freespace waves to guided waves or, conversely, from guided waves on a transmission line to freespace waves.

The ability of an antenna to receive as efficiently as it transmits is called *reciprocity*. This phenomenon allows the use of a single antenna for the reception and transmission of RF energy.

Antenna efficiency is the ratio of the output energy to the input energy. The efficiency may be greater than 90% but can never reach 100%. The loss of power is due to IR losses in the conductors of the antenna or to possible dielectric hysteresis.

Antenna directivity requirements vary with the usage. Manual reconnaissance search systems generally utilize omnidirectional or wide beam pattern antennas, while the direction finding (D/F) function is accomplished by directive antennas. Semiautomatic and automatic systems employ multiple directive antennas with overlapping coverage to effect the omnidirectional capability of the manual systems. In these antenna systems, search and D/F functions are combined. Jamming antenna radiation patterns are generally shaped to provide the best overall coverage for the aircraft.

Bandwidth and the associated response are of major importance in EW antenna design. An ideal EW antenna would have maximum efficiency, optimum coverage, and extremely wide bandwidth. Also, the aerodynamic considerations due to size, weight, and location of antennas are critical on high speed aircraft.

It is virtually impossible to satisfy all these requirements in any one antenna. Operational EW antennas are therefore limited in frequency coverage and radiation patterns due to design and installation factors.

RESONANCE AND DIMENSIONS

Electromagnetic waves travel through space at a speed of 300 million meters per second. The length of one cycle in space depends upon frequency and is called the *wavelength*. Mathematically, the length of an electromagnetic wave is expressed by the formula

$$\lambda = \frac{3 \times 10^8}{f}$$

Where λ = the wavelength in meters

f = the frequency in cycles per second

Since an electromagnetic wave travels on an antenna, the antenna, too, is considered to have wavelength. But, due to the electrical constants (inductance and capacitance) the movement of waves along an antenna is somewhat slower than wave movement in space and is expressed by the equation

$$\lambda = \frac{3 \times 10^8 \times .94}{f} \text{ meters}$$

Physically, therefore, an antenna is about 6% shorter than a half-wave traveling in space.

Length

An antenna of the correct length has the properties of a resonant circuit and presents pure resistance to the excitation circuit. An antenna having other than the correct length displays both resistance and reactance to the excitation circuit.

Resonance can be achieved through electrical compensation, by adding the opposite reactance into the circuit.

Diameter

Antenna *diameter-to-length ratios* as great as 1/10 are not uncommon in EW equipment. A large diameter increases the capacitance of the antenna and decreases the inductance. A smaller inductance lowers the X_L/R ratio, or Q of the antenna. A lower Q causes the resonance curve to be broader and gives the antenna a more uniform response to a wider band of frequencies.

Figure 6–1 compares the response of antennas having different diameter-to-length ratios. The bandwidths of antennas usually are defined in terms of their maximum-to-minimum frequency response. As an example, an antenna that has a usable response from 200 to 450 mc has a 2.5 to 1 bandwidth ratio.

THE BASIC ANTENNA

A half-wavelength conductor is the simplest radiating element. Considerable radiation occurs from this element because of its resonant characteristics and its ability to store large amounts of energy in induction fields. Resonance causes high voltages and high circulating currents which produce strong fields alternating around the antenna. The standing wave of voltage is high at the ends of the antenna and low at the center.

An examination of the current distribution curve on a half-wave antenna shows that the standing wave of current reaches maximum a quarter-cycle from the voltage maximum. The current intensities along the antenna are maximum at the center and zero at the ends.

In practical applications the ends of a half-wave antenna must be insulated due to the presence of high voltages, and the center of the antenna must have low resistance in order to minimize the I^2R losses due to high current.

IMPEDANCE AT INPUT TERMINALS

Practical antennas, like practical resonant circuits, have losses which must be replaced by the source. These losses make the input impedance of the antenna somewhat resistive. This resistance is a combination of two resistances—the resistance of the conductors, which is increased by the skin effect at high frequencies, and the radiation resistance.

Radiation resistance is a fictitious resistance which would dissipate the same amount of power in the form of heat that is actually dissipated as radiated energy. Because of radiation from an antenna, part of the fields escape into space. This makes it necessary for additional energy to flow into the antenna from the source to replace the part of the field that escaped. The energy lost is power (P), and its ratio to the square of the current (I) is the radiation resistance, R_r. Mathematically, it is expressed

$$R_r = \frac{P}{I^2}$$

Radiation resistance may be defined as the ratio of the power radiated to the square of the current in the antenna.

Radiation resistance and conductor resistance constitute the total input resistance of an antenna. To increase efficiency, it is desirable that a major portion of the input resistance become the radiation resistance. This can be accomplished through the use of large-diameter, low-reactance conductors. In practice, radiation ratios higher than 9:1 are obtainable.

POLARIZATION

The *polarization* of an RF transmission is determined by the angular relationship of the electrostatic (E) field to the earth's surface. There are two basic types: plane or linear polarization, where orientation of the E field occurs at a fixed angle; and circular polarization, where the resultant radiated E field rotates cyclically.

Plane Polarization

The plane polarized waves are employed in virtually all communications and most radar systems. They are normally propagated either vertically or horizontally polarized.

A vertically polarized wave is defined as a wave having an E field vibrating in a plane at

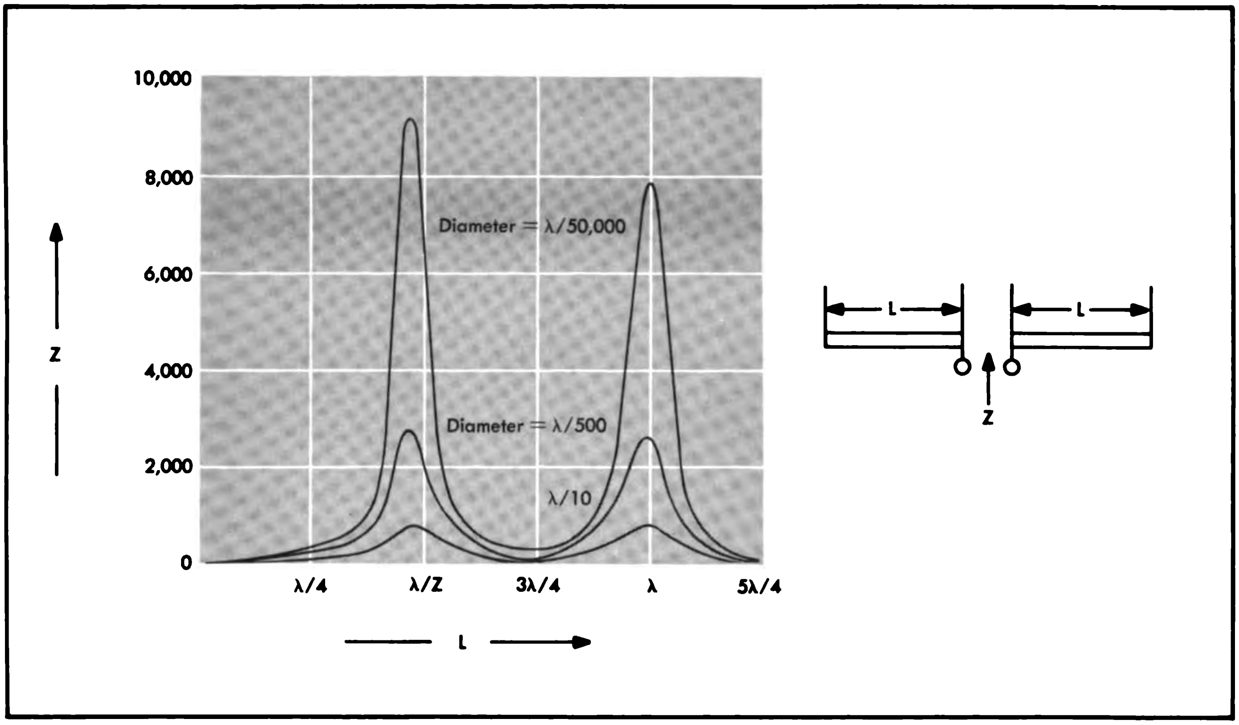


Figure 6–1. *Antenna Response*

an angle 90° from the earth's surface. A horizontally polarized wave has an E field that is parallel to the earth's surface.

VLF, LF, and HF bands normally benefit from vertical polarization. They are usually propagated along the earth's surface, either directly or by reflection. The earth's surface tends to short out a horizontal E field. It will therefore attenuate or dissipate horizontally polarized fields.

However, frequencies above the HF band will benefit from horizontal polarization. VHF frequencies and higher are propagated above the earth's surface as a direct wave but are troubled by interference from reflected ground waves. This reflected interference wave may be attenuated by the use of horizontal polarization.

The propagation of radar and countermeasures frequencies is another problem. One of the major considerations in the design of the radar antenna is jamming. Therefore, present-day radars often employ multiple polarization (polarization diversity). Jamming antennas, in turn, must be polarized to correspond with the polarization of the victim radar antenna, and reconnaissance systems must employ antennas that can intercept energy of any polarization.

Maximum intercept of energy will occur when the received electromagnetic wave polarity coincides with the receiving antenna polarity. However, the polarity at the receiving antenna does not always reflect the true polarity of the emitter antenna, since electromagnetic waves are sometimes rotated in space through refraction or multiple reflection.

Normally, this phenomenon does not occur at short distances where the radio path is "line-of-sight."

Circular Polarization

Circularly polarized antennas are widely used in active countermeasures equipment and, to a limited degree, in reconnaissance equipment.

The circularly polarized antenna has unique characteristics. It will respond equally to any plane-polarized wave whether the plane of polarization is vertical, horizontal, or any angle between. Also, the wave that it radiates has a resultant field component that continuously rotates in space as the wave is propagated.

Circularly polarized antennas that have a rotation effect counter to the rotation of a wave will not respond to the wave, just as horizontally polarized antennas do not respond to vertically polarized waves. The use of circularly polarized waves for jamming prevents radars employing polarization diversity from breaking through jamming by changing antenna polarization.

The circularly polarized wave may be generated by several methods, but only two will be discussed here. They are the wave-splitting and phasing techniques utilized in the electromagnetic horn, and propagation from a rotating field as generated by a helix antenna.

CIRCULARLY POLARIZED HORNS. The requirements for producing a circularly polarized wave from a given plane wave front, such as in the $TE_{0,1}$ mode of a waveguide, are to split the wave front into two mutually perpendicular phase fronts and to shift the phase of one with respect to the other by 90°. This technique is accomplished in the circularly polarized horn in the following manner.

An RF wave from a conventional waveguide, excited in the $TE_{0,1}$ mode, is propagated into a horn that splits the wave and shifts the fields into two components mutually perpendicular to each other. This is accomplished in the transition section as shown in figure 6–2. The two field components are then guided through a phasing section which slows one component more than the other, causing a relative shift in phase of the two components.

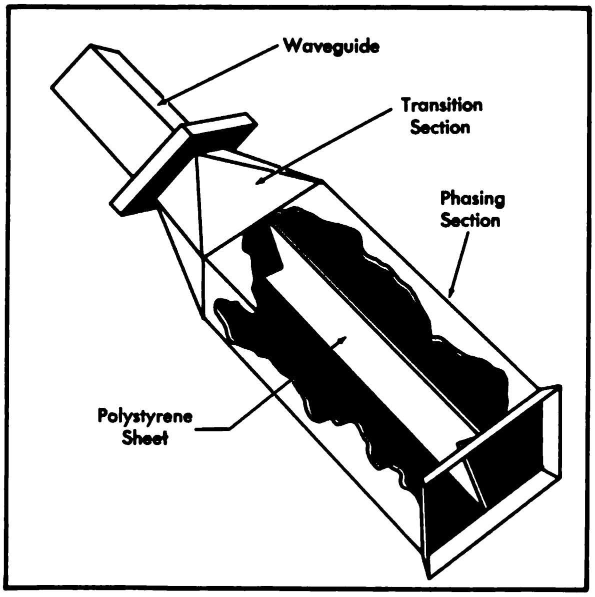


Figure 6–2. *Circularly Polarized Horn*

The velocity of the phase fronts may be affected in two ways: the phasing section may be rectangular so that the phase velocity of one component is greater than the other, or a polystyrene (or other suitable dielectric) sheet may be placed in the path of one wave so that it must travel through this dense dielectric, thereby slowing the phase front. In practice, both techniques are employed simultaneously, as shown in the phasing section of the illustration.

The phase shift does not remain exactly 90° for all frequencies that the horn will transmit; therefore, a truly circularly polarized wave is not always radiated.

If the wave components are not exactly 90° out of phase, the resultant radiated field will still have a rotating component, but it will be stronger in one plane axis than the other. Such a wave is an elliptically polarized wave. Waves that are slightly elliptically polarized are satisfactory for most jamming problems.

CIRCULARLY POLARIZED HELICAL ANTENNAS. Circularly polarized helical antennas are also wide band radiators suitable for active EW. Bandwidths as high as 2:1 have been achieved. They produce circularly polarized waves in a different manner from electromagnetic horns. The helix is especially suited to VHF and UHF type antenna installations.

The helical antenna may consist of one or several turns of a conductor (usually about two full turns) shaped in a helical form with dimensions that support approximately a wavelength per turn, as shown in figure 6–3.

The voltage field set up across the opening of a turn of the helix is ideal under the above conditions. The lines of the voltage field of the wave follow the form of the helix as it is propagated along the conductor; therefore, it revolves about the axis of the helix as it moves along the radiator. The energy is radiated in a beam along the axis of the helix as shown in figure 6–4.

Radiation of the phase fronts occurs throughout the time the wave is moving toward the open end of the helix. Thus, the radiated phase fronts have field components that are revolving at the period of the radiated

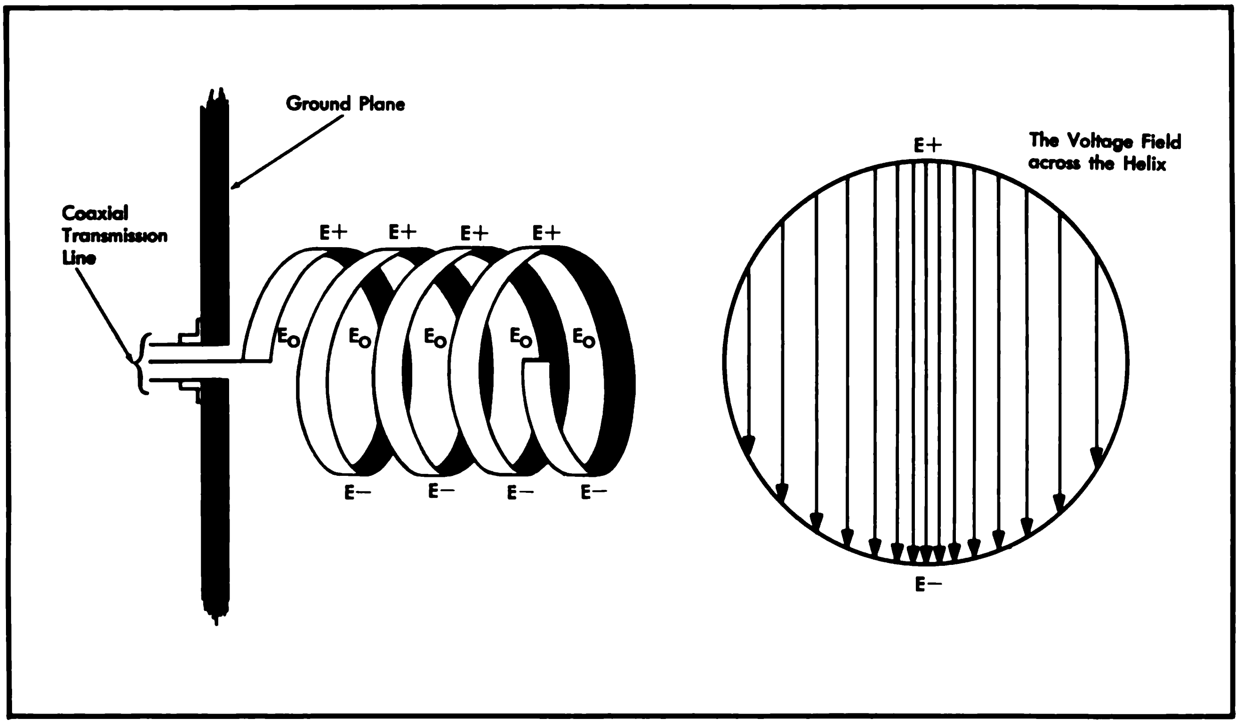


Figure 6–3. *Helical Antenna*

wave as a resultant of their motion down the helix during radiation.

The pitch of the helix is important in the phasing of the radiated energy to insure optimum radiation along the axis of the helix. A ground plane may be added to insure that all incidental radiation (radiation from reflected currents and voltages at the open termination of the helix) is reflected into the main lobe. Recessing the helix within a cavity accomplishes this more effectively and produces a mechanically strong unit that may be flush mounted.

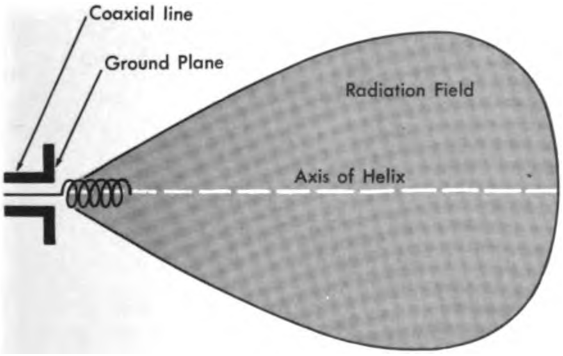


Figure 6–4. *Radiation from a Helix*

Spiral antennas are related to helical antennas. The bandwidth of spiral antennas may be very wide; 10:1 bandwidth ratios have been reported. The basic difference in electrical properties of the helix- and spiral-type antenna is the gradual divergence of the conductors of the spiral shape. This gradual change gives the spiral type its greater bandwidth.

The spiral antenna radiates a circularly polarized wave in a beam along the axis of the spiral normal to the plane of the spiral.

EW ANTENNAS

A large group of antennas are designed on the principle of gradual divergence or convergence of the boundary parameters of transmission lines. The common forms of such antennas of this type used in EW equipment are the electromagnetic horn, cones (single and biconical), spiral, scimitar, hatchet, leaky wave, and surface wave antennas.

Bandwidths from 1.5 to 1 through 10 to 1 are available in the above broadband antennas. The term "broadband EW antenna" is generally reserved for those antennas having essentially the same characteristics over a bandwidth of 2 to 1 or greater.

The electrical characteristics that are important in the effectiveness of EW antennas are:

- The radiation pattern from the antenna after it is installed.
- The bandwidth to which it will respond.
- The type of polarization to which it will respond.

The physical characteristics of ECM antennas are important from the standpoint of size, weight, and the effects they may have on aircraft performance. External antennas must be ruggedized to withstand aerodynamic stresses, and must have heavy radiating elements to provide satisfactory power and bandwidth capabilities. But these same design considerations degrade aircraft performance.

Low drag requirements for high performance vehicles make flush-mounted EW antennas desirable; but in most cases flush-mounted antennas do not provide satisfactory radiation patterns. Generally, physical characteristics of EW antennas are not compatible with aircraft aerodynamic considerations. For this reason, present EW antennas leave much to be desired and require further design breakthroughs to satisfy operational requirements.

Electromagnetic Horns

The electromagnetic horn may be designed to give the wide angle, solid coverage required of jamming transmission systems, or it may be constructed to produce a relatively narrow beam for limited area coverage. Such antennas are said to "look" in discrete angular sectors.

It is expected that such antennas will result in 10 to 100 times more jamming power by instantly radiating jamming energy back in the direction from which the received signal came. Instantaneous EW directional antenna systems would insure coverage of all sectors about the aircraft while making the most effective use of the radiated jamming power.

The electrical characteristics of an electromagnetic horn are flexible. It may be made to support any plane or circularly polarized wave.

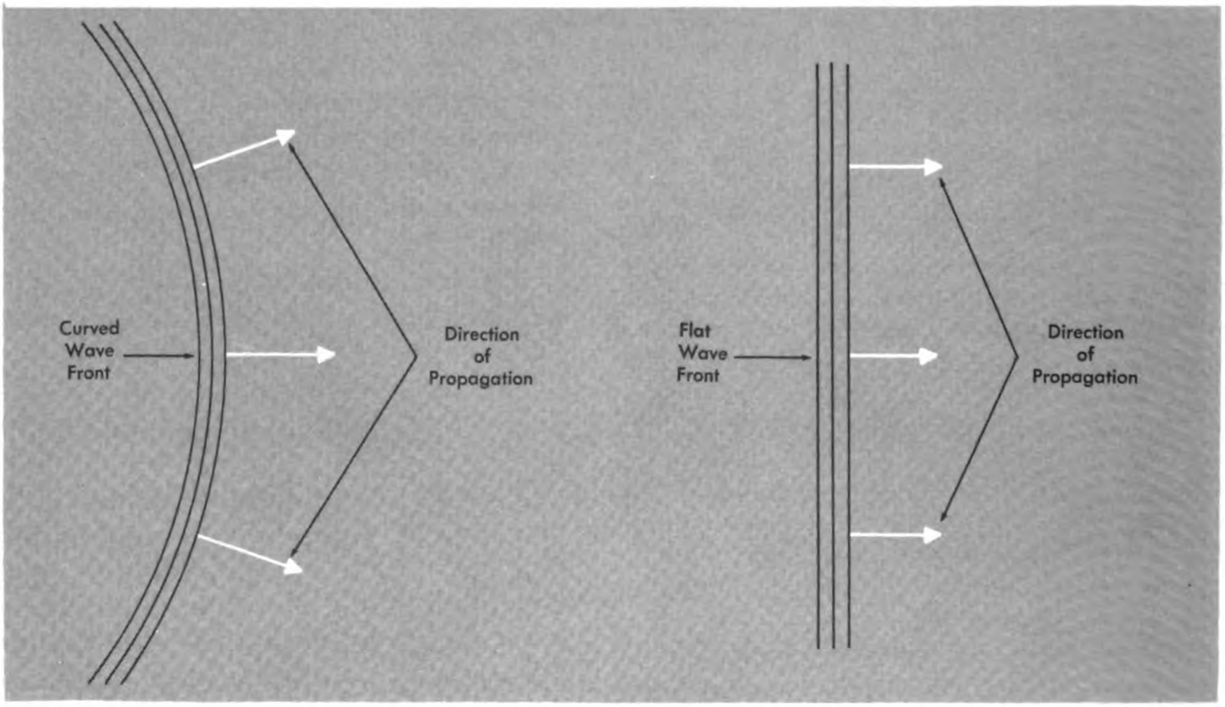


Figure 6–5. *Propagation of Curved and Flat Wavefronts*

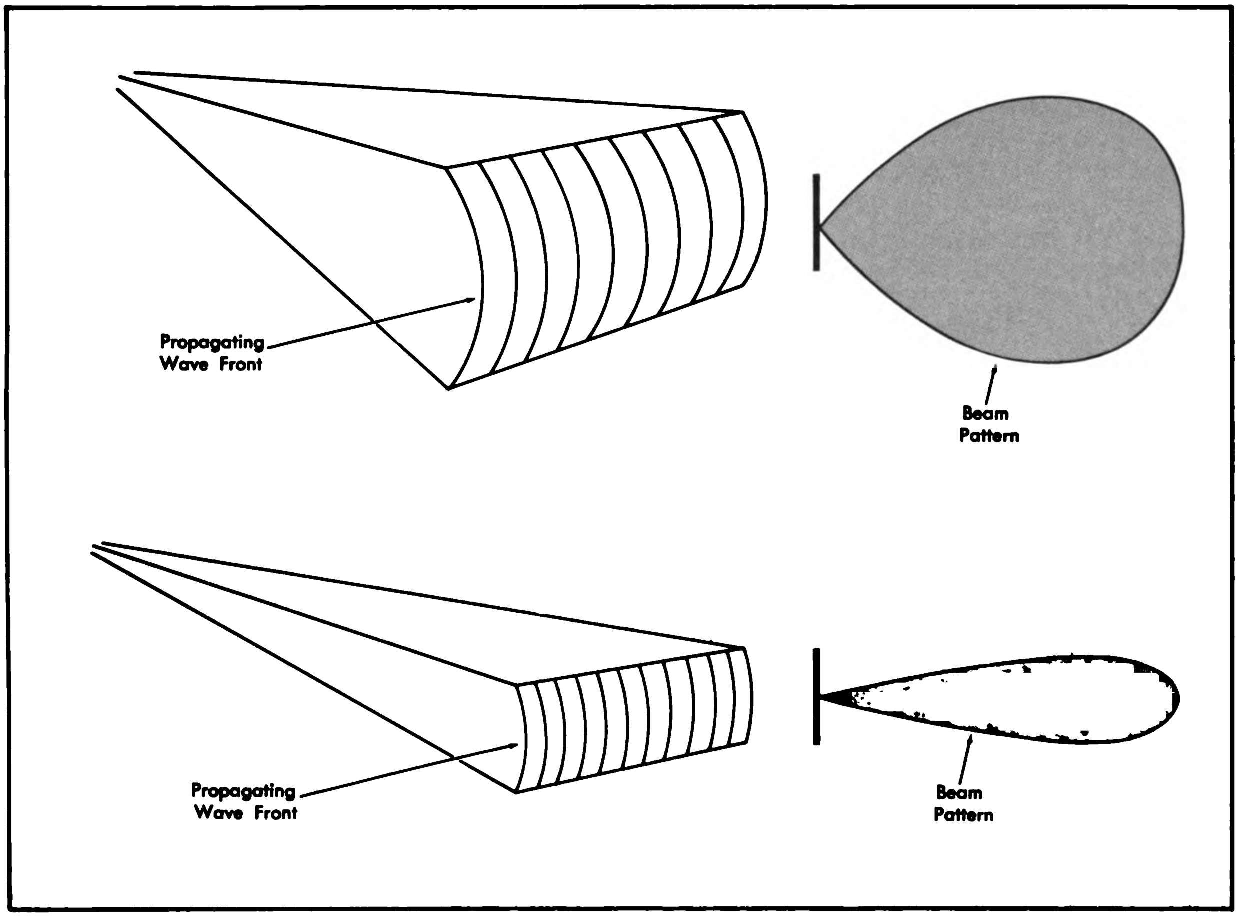


Figure 6–6. *Flare Angle*

The horn is basically a waveguide transformer. The waveguide is flared in order to effect a gradual change from guided waves to freespace waves. If the aperture of the horn is a wavelength or more and the taper is not too great, the transition from guided waves to freespace waves is accomplished without appreciable reflections, since many small reflections over a wavelength or more tend to cancel.

The limits of the rate of flare (change in cross-sectional size) are quite wide and have little effect on bandwidth. The shapes of horns are distorted in many ways, but they must always retain the gradual change per wavelength configuration if they are to have wide band characteristics.

FLARE ANGLE AND APERTURE. The beam width is determined by the flatness of the phase front of the radiated wave. This results from the phenomenon of propagation of electromagnetic energy whereby the wave is always propagated perpendicular to the phase front. This concept is shown in figure 6–5.

The field within the horn moves along an axis bisecting the horn. The curvature of the phase front is a result of the distances traveled by the wavefront from the apex of the horn. The extremities of the field have traveled the same distance as the center of field, but are lagging because they follow the walls of the horn.

It can be predicted then that the wave will continue to expand (as it propagates) at a rate that is directly related to the curvature of the phase front and, hence, the flare angle of the horn. A wider flare angle will cause the phase front to be of greater curvature, thereby generating a wider beam. This general concept is illustrated in figure 6–6, which compares two electromagnetic horns of different flare angles.

Electromagnetic horn radiators tend to

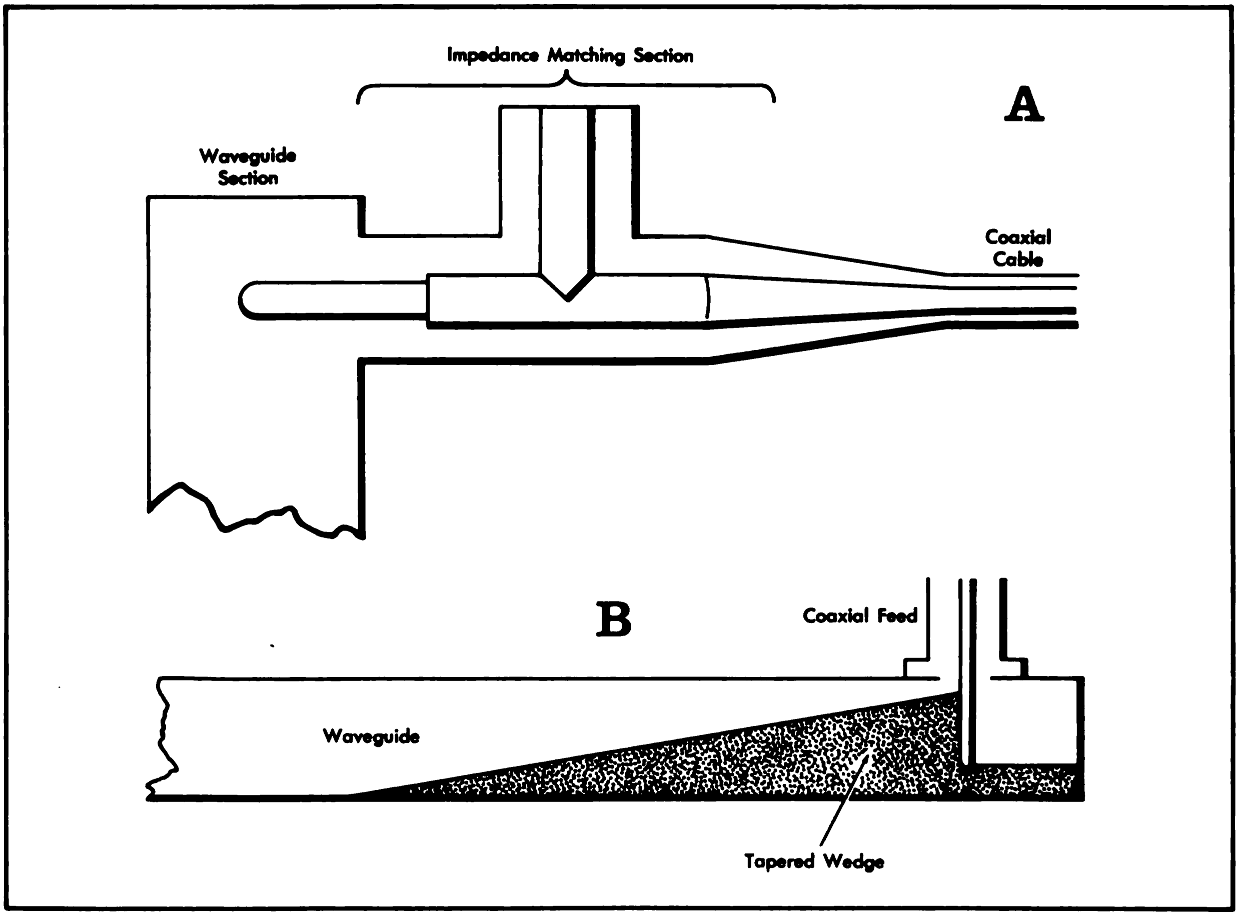


Figure 6–7. *Coaxial-to-Waveguide Impedance Matching*

maintain a given beam width. This constancy of pattern is a result of two compensating phenomena.

In all directive type antennas the beam tends to become narrower as the aperture-to-wavelength ratio increases, or as the operating frequency of a given antenna is increased. This phenomenon tends to decrease the beam width at the higher frequencies of the horn type antennas as well as other types; however, the phase front radiated from horns has an opposite effect. The beam tends to widen as the frequency increases due to a greater variation in the phase front radiated.

The increase of aperture is the dominant effect and a narrower beam is generated at the higher frequencies, but the beam angles of horn radiators are much less sensitive to frequency changes than are other directive types of radiators. Beam angles of greater than 80° may be generated.

METHODS OF EXCITING. The method of feeding horns may be either from a waveguide or a coaxial transmission line. Coaxial lines are preferred in electronic warfare equipment in order to make the installation of the equipment more flexible. The coaxial transmission line is first matched to a waveguide, and then the magnetic horn is fed from the waveguide.

The matching of a horn to a waveguide is not difficult, since the dimensions of the input end of the horn may be drawn down to match the walls of the waveguide. The gradual taper of the sides of the horn reduces the reflections to a negligible value over a wide band.

The impedance matching methods used to transform from coaxial transmission lines are often the limiting factor in the overall system frequency response. Wide band coupling probes may be constructed by maintaining large diameter-to-length radiating stubs tapered into prescribed coaxial transmission line

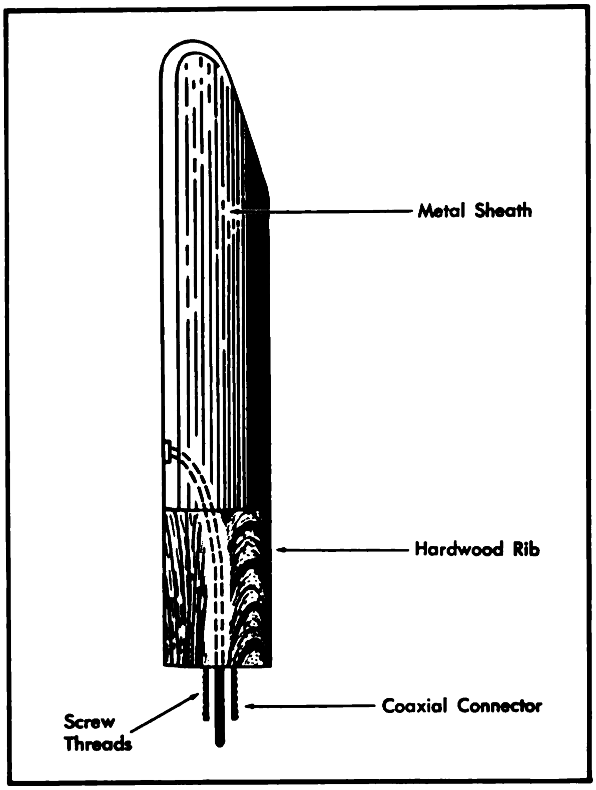


Figure 6–8. *Stub Antenna*

dimensions. Matching stubs are sometimes required to cancel reflections from the probe.

The illustration A in figure 6–7 shows a coaxial-to-waveguide matching transformer with a matching stub. Another type of coaxial-to-waveguide connector is a tapered or wedge-shaped section of waveguide connected as shown in the B illustration.

The center conductor of the coaxial line is extended through the wall of the waveguide and makes contact with the opposite wall at the narrow opening of the wedge. The transition from the coaxial Z_0 to the waveguide Z_0 is gradually made throughout the wedge-shaped section. This type of transformer is adaptable to very wide bandwidths and is of great utility in broadband systems.

Stub Antennas

The typical stub antenna, as you can see in figure 6–8, consists of a streamlined hardwood rib with a metal sheath on the outside which acts as the radiating surface. The inner surface of the sheath is connected to the center conductor of a coaxial transmission line which feeds the antenna through a coaxial fitting in the base of the mast. The outer conductor of the coaxial line is connected to the metal skin of the aircraft.

The stub antenna is omnidirectional in the horizontal plane. However, the exact shape of the radiation pattern varies somewhat with the location of the antenna on the aircraft. This is due to the fact that portions of the aircraft serve as reflectors for the antenna.

The stub antenna is about a quarter-wavelength long electrically. Its radiation resistance is approximately 50 ohms, and it is often fed with a 50-ohm coaxial line without matching devices.

A wide bandwidth is achieved by stub antennas in spite of the electrical simplicity of their construction. The stub is a common antenna used for ECM.

Sleeve Antennas

A sleeve antenna consists of a tubular conductor or sleeve. The exterior of the sleeve is used as a radiating element, and the interior is used as the outer conductor of the coaxial transmission line that feeds the antenna. The

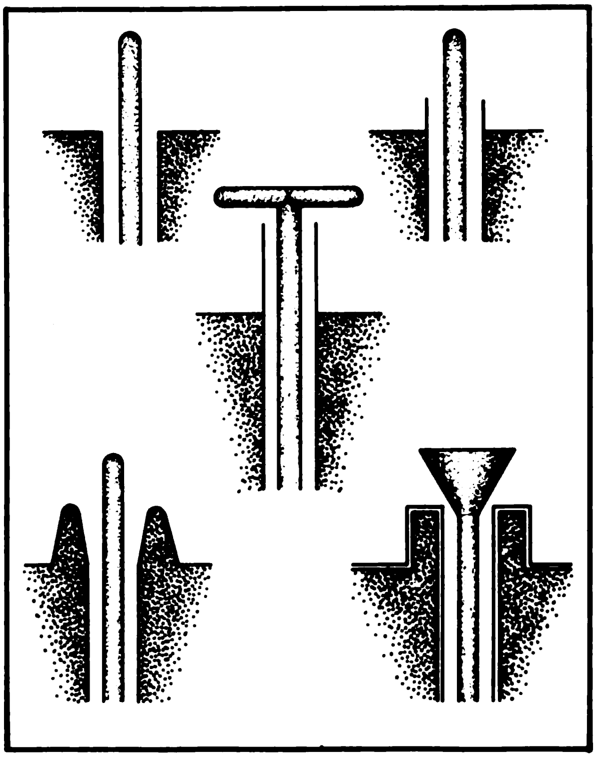


Figure 6–9. *Sleeve Antenna*

sleeve may be as long as any portion of the total antenna.

Two of the antennas shown in figure 6–9 are extreme in sleeve length. At A, the sleeve length is zero and the sleeve antenna is reduced to an ordinary cylindrical stub. This stub, which is the radiating element, is a continuation of the inner conductor of the coaxial line.

The other extreme is illustrated at C. In this case, the sleeve makes up the entire radiating portion of the antenna.

All the sleeve antennas shown here are unbalanced, since their relation to the ground plane corresponds to the relation existing when a stub operates against a ground plane. These sleeve antennas are therefore called *sleeve stubs.*

The type of sleeve antenna most commonly used is made up of elements of uniform cross section. When sleeve antennas are short in terms of wavelength, the resulting patterns are the same as those obtained from stubs of the same lengths.

A sleeve dipole may be bent to form a V in order to increase the directivity of its pattern. If a bent sleeve dipole of this sort were mounted under an aircraft, the radiation would be directed downward in a broad single-lobed pattern free from deep nulls.

Frequently, the sleeve dipole is also used with a reflector in order to obtain a directional pattern. This type of assembly is particularly adaptable to broadband operation since neither the spacing between the reflector and the antenna nor the dimensions of the reflector is critical.

Sleeve dipoles are the most suitable antennas for constructing crossed-element phased antennas for broadband performance. A crossed-element phased antenna, called a turnstile, consists of two dipoles, bisecting at right angles and fed with equal currents 90° out of phase. Along the axis of symmetry of the antenna, the polarization is circular.

Two loops may be used instead of two dipoles. Another type uses two V dipoles instead of straight dipoles.

Slot Antennas

A slot antenna may be considered as a waveguide terminated in a horn which has a flare angle of 180° to the ground plane. The dimensions of the slot must conform to wavelength under the same rules as those which cover waveguide dimensions.

Current flows not only in the slot but in the ground plane as well. Thus, the radiation area includes the area of the ground plane. Many of the ECM flush-mounted antennas are in this classification.

Electromagnetic waves can be introduced through the aperture of the slot by a variety of methods. The manner in which the slot is excited usually determines the frequency sensitivity and behavior of the antenna.

One of the simplest methods of feeding is to connect the individual conductors of a coaxial line to opposite sides of the aperture as shown in A in figure 6–10. A section of waveguide may be used as shown in B. Another method is shown at C, where a slot is cut in the surface of a waveguide. With this method waves can be introduced into the waveguide by means of a probe extending into the interior; the energy within the guide then excites the slot.

The most important practical advantage of slot antennas is the fact that the feed section required for excitation of the slot may be placed below the surface of the ground plane in which the slot is cut. Nothing protrudes above the surface of the ground plane, and the slot itself may be covered with a dielectric sheet so that the physical opening is eliminated. This in itself resolves many of the problems of aircraft antenna design, such as the problems of wind drag and mechanical strength.

The radiation pattern produced by a simple slot antenna consisting of a narrow rectangular slot cut in an infinite plane metal sheet is closely related to the pattern produced by a thin flat dipole that would just fill the aperture. The only difference is one of polarization. The electric field distribution of a slot radiator is the same as the magnetic field distribution in the pattern of an equivalent dipole.

The size of the ground plane, in which the slot is cut, does affect the regularity of the radiation pattern. However, if the aircraft presents a ground plane which is large compared

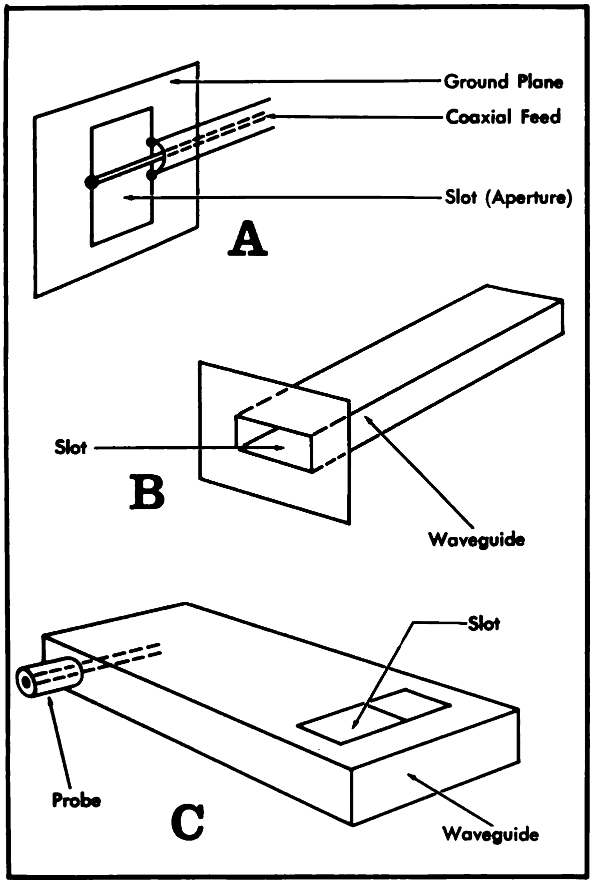


Figure 6–10. *Slot Antennas*

with the wavelength, a fairly smooth broad pattern results.

The effects of large obstacles present in aircraft installations of slot antennas, such as wings, control surfaces, or engines, can be determined by line of sight considerations.

Radiation occurs from the side of the ground plane opposite the waveguide or cavity.

Cavity-fed slot antennas can be reduced in size by capacitance loading. One way of loading is to fill the cavity with a dielectric.

Leaky Wave Antennas

Leaky wave antennas are another answer to the aerodynamic problems of high performance aircraft. This form of antenna is an internally mounted waveguide section, tapered and provided with slots or holes along one side. As the wave travels down the waveguide section, it leaks out gradually through the perforations and is radiated into space.

The direction and width of the beam of energy produced in this type of antenna can be controlled by the number of perforations, the rate of leakage, or the slot width, and the phase velocity (determined by the dimensions of the waveguide section and the frequency).

It can be seen in figure 6–11 that this form of antenna is a converging type of transformer, whereas the types discussed previously had radiating surfaces that were diverging in form. The gradual change characteristic is maintained, however, giving this leaky wave antenna wide band characteristics.

The polarization may be either vertical or horizontal, depending on the mode of excitation. Figure 6–11 illustrates a vertically polarized mode of excitation.

Surface Wave Antennas

The surface wave antenna is a wide band antenna having highly desirable physical characteristics for high performance type areospace vehicles. It consists of a dielectric-clad metal surface along which a wave is propagated.

Surface wave antennas radiate in an endfire mode. Vertically or horizontally polarized waves may be propagated from the surface wave antenna, depending on the choice of surface structure. Dielectric slabs having two layers of different dielectric constants and

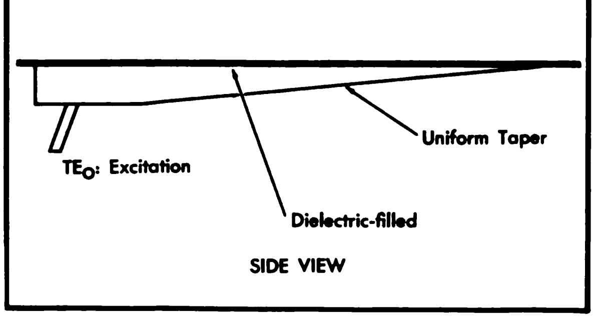


Figure 6–11. *Leaky Wave Antenna*

corrugations are used to achieve the desired effects.

Some beam pattern problems are associated with endfire surface type radiators, such as the leaky wave and the surface wave radiators. The physical characteristics of these radiators place them in very close proximity to the skin of the vehicle. The reflections from these curved surfaces and other discontinuities in the vicinity of the radiators have had some undesirable effects on radiation patterns.

These problems are not insoluble, but they do point out the need for careful analysis of any new antenna installation before it can be considered acceptable. Laboratory results are not necessarily reproduced in the field.

Scimitar Antennas

Scimitar antennas are easily adapted to match coaxial transmission lines. Their form is illustrated in figure 6–12.

Note the exponential type variation in the blade width from the center conductor of the coaxial line to an area where the blade is connected to the ground plane. This tapered radiating loop blade has the characteristics required for a wide bandwidth of operation (a gradual changing radiation aperture) and at the same time is a sturdy mechanical device that offers little wind drag to its thin blade-like construction.

A special version of the scimitar is the hatchet antenna, also shown in figure 6–12. The hatchet shape alters the termination of the blade, thereby changing the areas of discontinuity of the blade.

Through experimentation with various shapes and forms, a shape has been developed that has optimum bandwidth and radiation pattern.

The special shapes of hatchet and scimitar type antennas are similar to the tilted cone and capped cone techniques employed in earlier developments of EW antennas, but offer better physical characteristics for high performance aircraft. They can be mounted to provide vertical or horizontal polarization. Their bandwidth ratios may be higher than 2.5 to 1.

Direction Finding Antennas

A direction finding antenna is a receiving antenna that extracts energy from passing electromagnetic waves in such a way that the

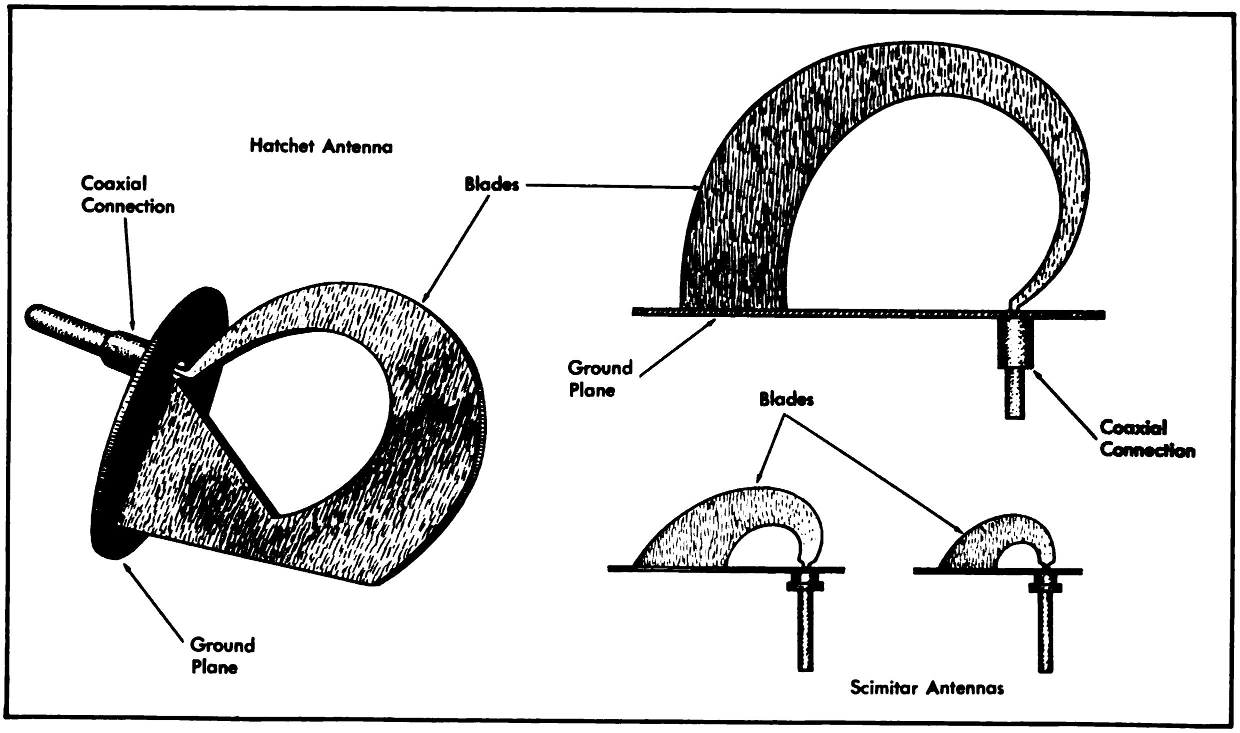


Figure 6–12. *Hatchet and Scimitar Antennas*

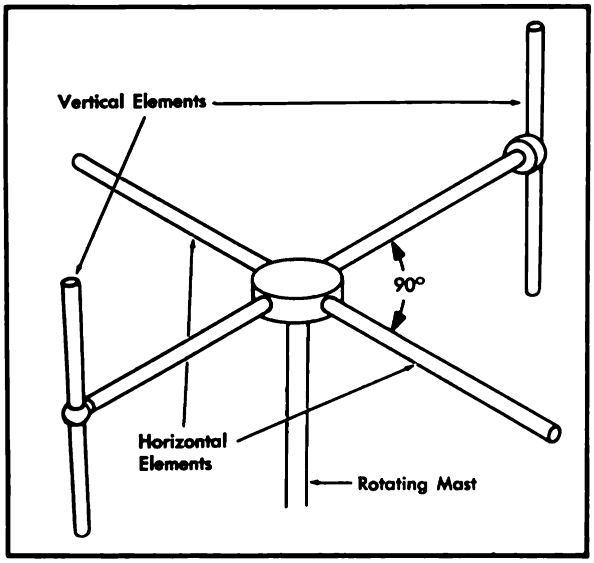


Figure 6–13. *Adcock Array*

direction from which the energy arrives can be determined.

ECM antennas must perform suitably at frequencies above 50 mc. Manually operated airborne D/F antennas usually have motor-driven rotable assemblies or spinners.

Adcock Array. When a half-wave linear element for frequencies about 150 mc is mounted horizontally and rotated, bearings can be taken on horizontally polarized sources because minimum response indicates direction. Since the directional pattern of the half-wave element has two minimums, there is a 180° ambiguity. However, for airborne applications this is not objectionable since the speed of the aircraft with respect to the source will quickly resolve the ambiguity.

To take bearings on both horizontally and vertically polarized sources, the antenna must be converted into an Adcock antenna. An Adcock antenna (shown in figure 6–13) is formed by adding two vertical half-wave elements (spaced about a half-wavelength apart) to the half-wave element.

Bearings then can be taken on either horizontally or vertically polarized waves. The direction of the nulls of the vertical elements in the horizontal plane coincide with those of the horizontal elements, so no bearing shift is apparent when the source shifts from horizontal to vertical polarization.

Electrical connection to the antennas is by means of twin coaxial transmission lines. A balun couples each feed to each coaxial cable.

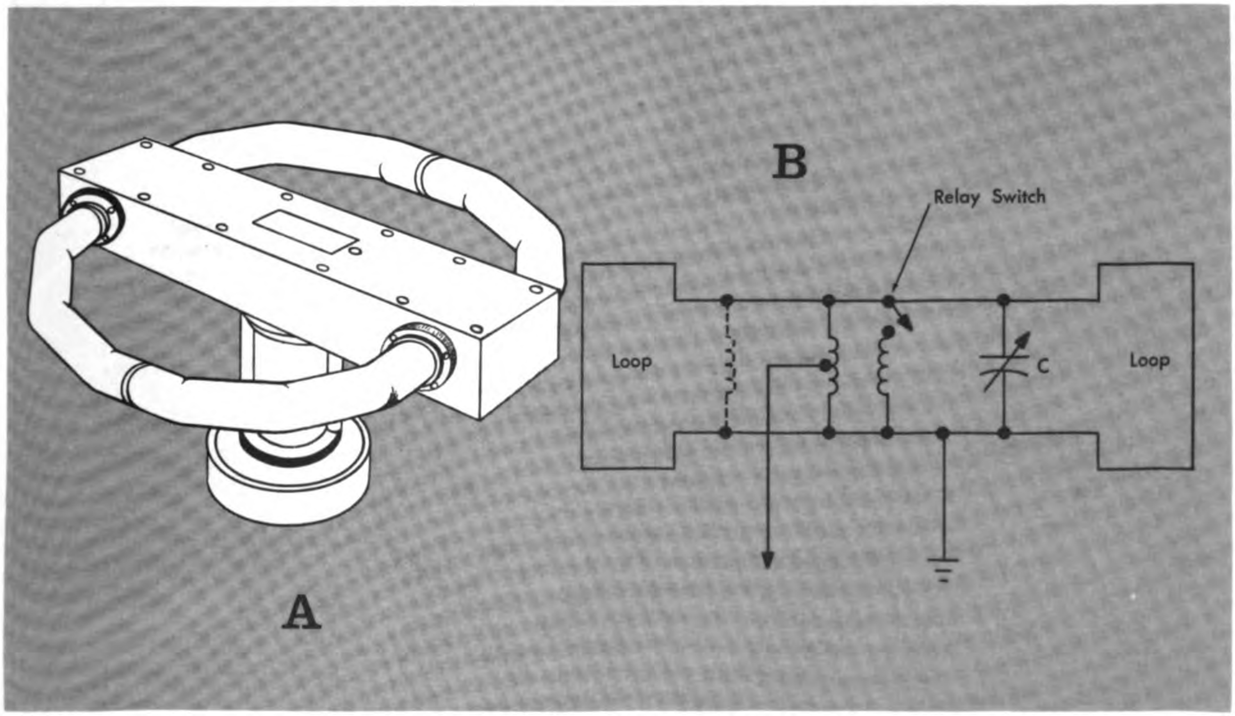


Figure 6–14. *Double Loop Spinner*

Since there is no rotating joint, the antenna cannot be rotated through more than 360°. To cover various frequency ranges, different sizes of arrays can be interchanged on the masts.

Double Loop Spinners. The double loop spinner type of D/F antenna was designed for the band of frequencies between 50 and 300 mc.

The double loop, as shown at A of figure 6–14, is mounted on a vertical column. The center portion contains inductance coils, a frequency change relay, and a variable capacitor that tunes the loop to resonance. The capacitor is tuned remotely by means of a pair of synchros. An electric motor drive rotates the spinner at speeds of 100 to 300 rpm. The RF transmission line is connected to the receiver by means of a rotating joint.

The two loops are connected in opposition so that the radiation pattern is a figure eight, with minimums in the direction of the center

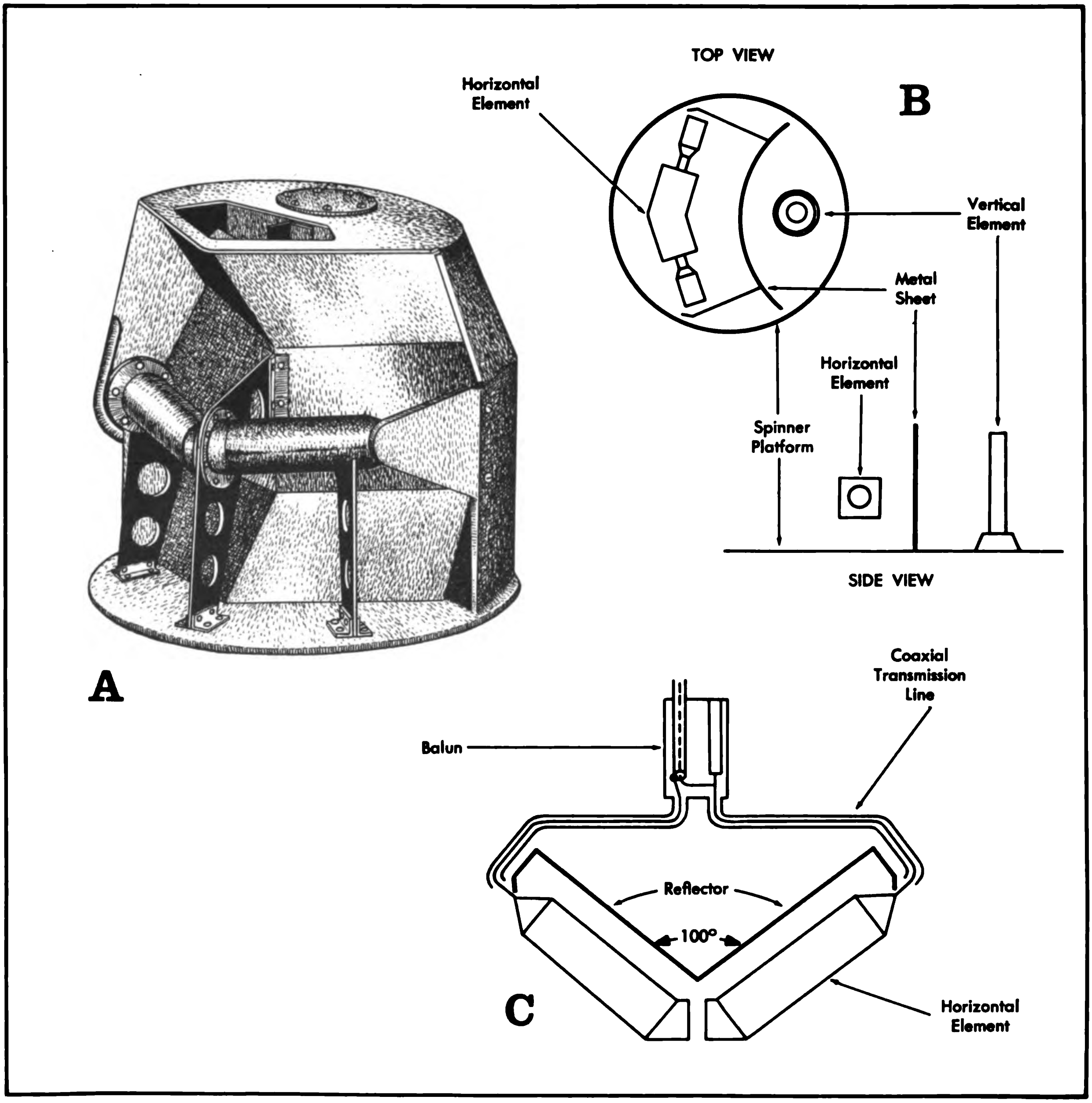


Figure 6–15. *Corner Reflector Spinner*

horizontal member and maximums out from the ends of the loops.

Corner Reflector Spinners. Corner reflector spinners are useful in D/F work for frequencies between 100 and 1000 mc.

A metal reflector is placed between a vertical and a horizontal antenna, as shown in figure 6–15. Either the vertically polarized antenna or the horizontally polarized antenna can be connected to the receiver, as desired.

The directivity and bandwidth of either antenna is increased by shaping the reflecting surfaces presented to each antenna. This results in the type of assembly shown at A in the illustration (corner reflector spinner with a horizontal V antenna).

A vertical sleeve antenna, supported by a plastic cover, is mounted in a corner reflector of 100° internal angle as shown at B. The reflector sides and the truncated corner make the reflector approximate a parabolic contour, and the focusing effect is very similar to that of a parabolic reflector.

The horizontal elements in the form of a V may be placed parallel to the back surfaces of a corner of the reflector as shown in C. These surfaces are so shaped that they present to each arm of the horizontal element the form of a truncated 90° corner. The corner focuses the horizontally polarized energy onto the antenna elements, thereby increasing directivity.

The ends of the horizontal elements are connected to the center conductor of a coaxial cable as shown at C. The cable from each horizontal element connects through a balun to a coaxial line for transmission to the receiver.

An RF relay switches the receiver to either the horizontal or vertical antennas. To eliminate a 180° pattern shift when antennas are switched, another relay reverses the pattern on the operator's indicator.

This type of spinner rotates at speeds up to 300 rpm. As the frequency of the source is increased, the pattern tends to become sharper with smaller back lobes.

Parabolic Spinners. At frequencies above 1000 mc it is practical to use parabolic reflectors.

A spinner of this type has both a horizontal and a vertical collector, each with its parabolic reflector. The reflectors are placed back to back as shown at A in figure 6–16. This type spinner .employs sleeve dipoles at these frequencies.

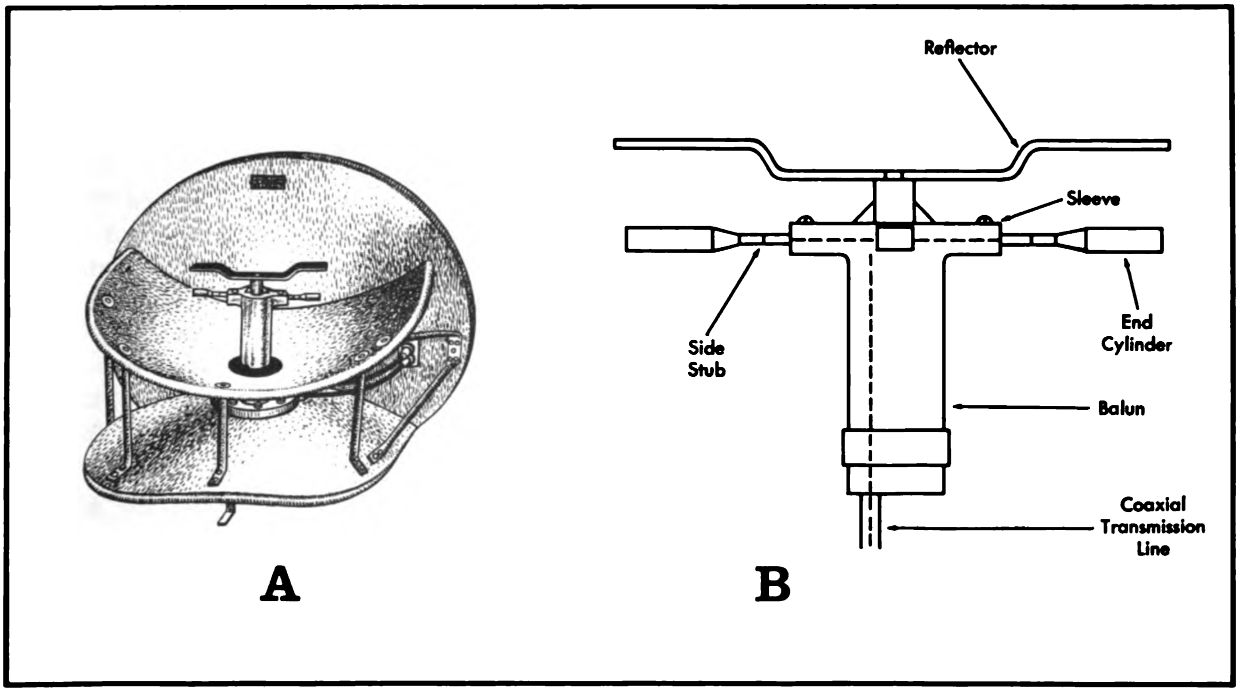


Figure 6–16. *Parabolic Spinners*

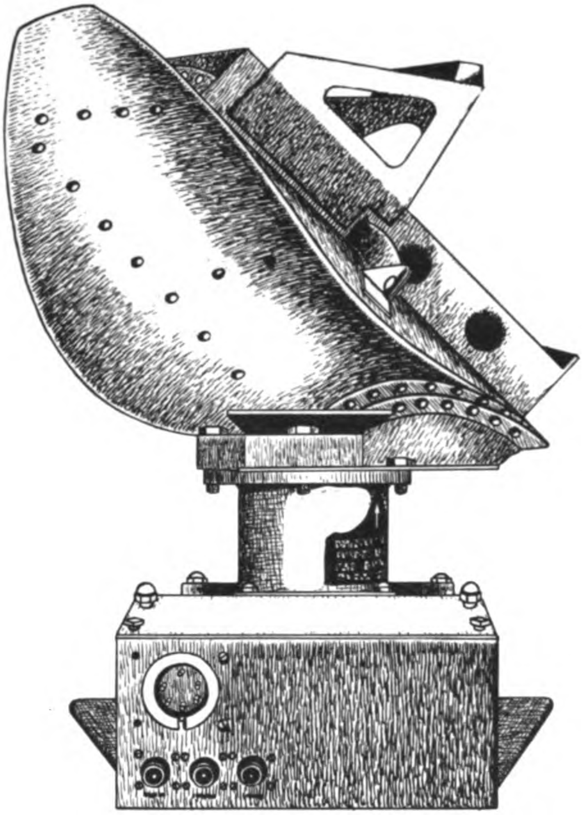


Figure 6–17. *Rotating Reflector*

Rotating Reflector. D/F horn assemblies with rotating reflectors operate effectively over frequencies from 5000 to 12000 mc.

In figure 6–17, the antenna collector is a circularly polarized horn. The horn remains stationary and is located within the surface of the aircraft. Energy is deflected into the horn by a rotating parabolic reflector, which rotates around an axis through the horn and is mounted at a 45° angle at the mouth of the horn.

The antenna has equal response to either vertically or horizontally polarized signals. It is also responsive to circularly polarized waves.

This type of assembly does not need a rotating RF joint. Since it responds equally to horizontally or vertically polarized signals, the need for an RF relay is also eliminated.

The parabolic reflector is mounted on a motor-driven ring gear that revolves around the axis of the horn. A synchro turning at the same speed as the antenna provides the operator's indicator with the instantaneous bearing of the spinner.

CHAPTER 7

Missiles

National policy places a large share of the burden of deterring war on the USAF. Furthermore, should deterrence fail, the Air Force must bear the brunt of deciding the outcome.

The decisive phase of any future war will be fought with the weapons on hand. This requires operational aerospace vehicles—aircraft, missiles, and space systems—and the necessary support equipment to make them effective weapons.

Electronic warfare plays an important role in aerospace systems by making them more effective weapons. The defensive systems officer (DSO) is given the job of penetrating the enemy electronic defenses and countering ground and air launched missiles. Missiles must be designed to avoid ECM. Antimissiles must cope with EW techniques, and space vehicles gather ELINT information.

All these applications underscore the importance of the EW officer having job knowledge of aerospace systems. This chapter is devoted to missiles and their guidance systems.

Guided missiles are defined as self-propelled, unmanned vehicles, operating above the surface of the earth and having self-contained means of altering the trajectory or flight path.

The Germans were the first to effectively use guided missiles. During World War II, the Germans' V–1 and V–2 (called Vengeance 1 & 2), although they had poor guidance and terminal accuracy, were true guided missiles. They caused considerable anxiety and damage and generally lowered the morale of the people of London.

The Germans also developed operational missiles for use against bombers before the end of World War II.

CLASSIFICATION OF GUIDED MISSILES

To study missiles in a systematic manner, it is necessary to identify or classify them in some manner. There are several methods of classification in use at the present time. The most common method uses "A" for air, "S" for surface, and "U" for underwater.

When used in a combined form, the first letter designates the intended launching point of a missile, and the second letter designates the intended destination. These letters, used in combination with the letter "M" for missile, classify the use of missiles as follows:

SAM	surface-to-air missile
AAM	air-to-air missile
ASM	air-to-surface missile
SSM	surface-to-surface missile
AUM	air-to-underwater missile
SUM	surface-to-underwater missile
USM	underwater-to-surface missile
UAM	underwater-to-air missile

Another form of classification adopted by the Air Force has the following designations: TM–61, SM–62, SM–64, SM–65, IM–99, GAR–1, and GAM–63.

TM	tactical missile
SM	strategic missile
IM	interceptor missile
GAR	guided aircraft rocket
GAM	guided aircraft missile

Missiles are also classified by Mach number. This is a comparison of the velocity of a missile to that of the speed of sound at sea level. Mach 1 (sonic) is approximately 740 mph at sea level; subsonic is below Mach 1; supersonic is above Mach 1; and hypersonic is more than five times the speed of sound.

Types of guidance can also be used to classify missiles. In this method of classification, the missiles are identified as active, semiactive, or passive in accordance with the type of terminal guidance used.

All of these systems depend upon the detection of some type of radiation as a means of guiding the missile to the target. The missile may detect radiation given off by the target automatically (passive type), or it may detect reflections of radar signals transmitted either by the missile itself (active type) or by ground-based equipment (semiactive type).

Guided missiles may also be classified in terms of their range, *long* or *short*. Under this method of classification, an ICBM with a range of less than 5000 miles is considered short range. A missile having a range greater than 5000 miles is classed as a long range ICBM.

The practice of giving a popular name to different types of aircraft, in addition to their technical designation, has been in existence for many years in the Air Force. The following popular name groups are authorized for missiles.

AAM — winged creatures (excluding birds of prey and game birds)
ASM — birds of prey
SAM — mythological terms
SSM — astronomical terms
Target drones — game birds or hunting terms

Exceptions to this type of grouping are missiles named prior to the use of this system; they retain their original names. An example of such an exception is the Lark.

PROPULSION

The propulsion system of a missile includes the engines, all necessary associated equipment to insure ground and inflight engine operations, and the fuel or propellant necessary to propel the vehicle.

The different forms of these propulsion systems are numerous, each having individual characteristics that suit it to a particular application. Some of the important limitations of guided missiles affected by the type of propulsion are maximum altitude, speed, and range. Engines and propellants require further discussion.

Engines

All of the engines used in missiles are of the jet propulsion type. There are two major types of jet propulsion engines, rocket and ducted types.

ROCKET ENGINES. Rocket engines are self-contained; that is, all of the materials which are necessary for operation are contained within the unit. The necessary materials are fuel and oxidizer. An oxidizer is a substance which contains the oxygen necessary for combustion of the fuel; therefore, the operation of a rocket unit is independent of the atmosphere.

AIRBREATHING ENGINES. In the case of airbreathing engines, the medium (air) through which the missile passes is taken into the unit and accelerated to a greater momentum by thermal means prior to ejection. One such type is the mechanical compressor unit in which the working fluid (air) is compressed, burned, and allowed to expand through an exhaust nozzle. The compression is usually achieved by some form of rotary compressor wheel driven by a turbine.

The sketch of the turbojet engine in figure 7–1 illustrates the principles of operation. Hot gases that result from the combustion of fuel and air in the combustion chambers strike the turbine wheel, causing it to rotate. The rotary motion is transferred by means of a shaft to the compressor wheel which compresses the air, forcing it into the combustion chamber where it expands as a result of combustion with fuel from injectors.

Another type of ducted engine propulsion is the *pure duct*. In this type, compression of the working fluid is obtained by proper design of the intake section of the duct. Here again, burning takes place and is followed by high-speed expansion through an exhaust nozzle.

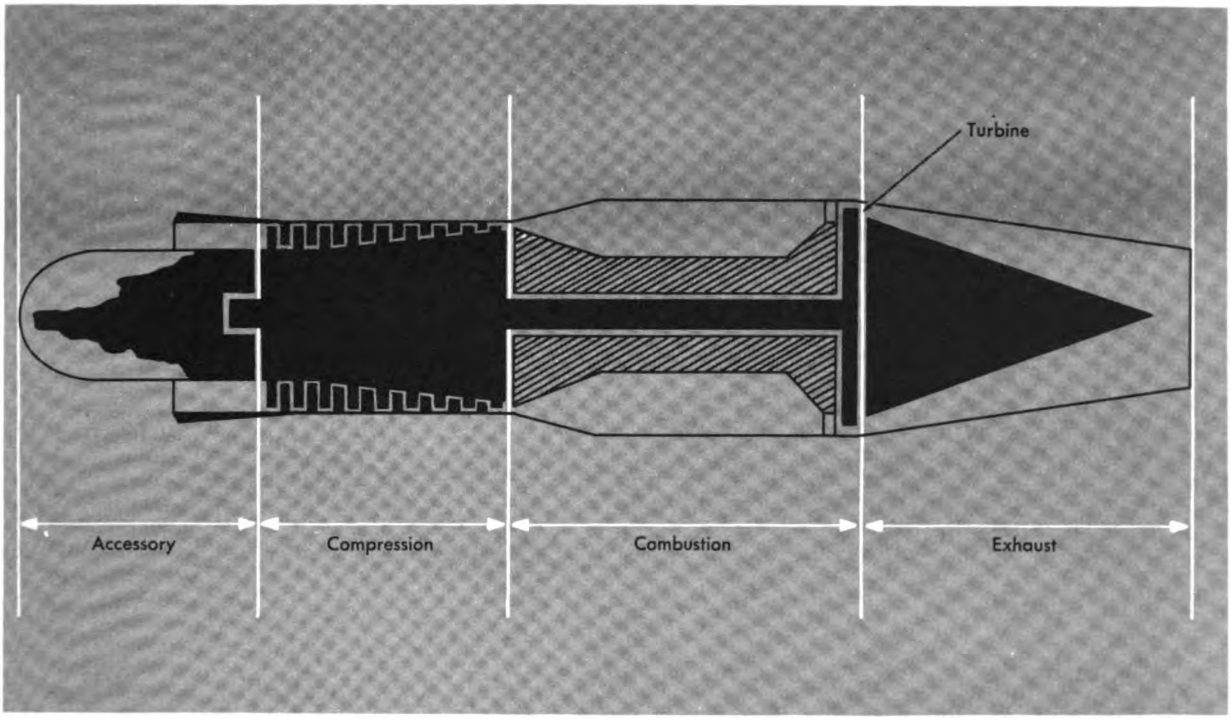


Figure 7–1. *A Turbojet Engine*

The ramjet engine shown in figure 7–2 uses this type of propulsion.

A third type of duct propulsion is the intermittent, or pulsejet, unit. This engine also obtains pressure and velocity changes in the fluid medium by proper design of the intake section of the duct. It differs from the two previous types in that the flow of air and heat-giving fuel is *intermittent*, or in *cycles*.

Propellants

Thrust is developed as a result of energy released in the jet-propulsion engine. A large quantity of readily available energy is found in a variety of fuels used in jet engines to impart thrust to propel the missile. These materials and the oxidizers with which they react are called propellants.

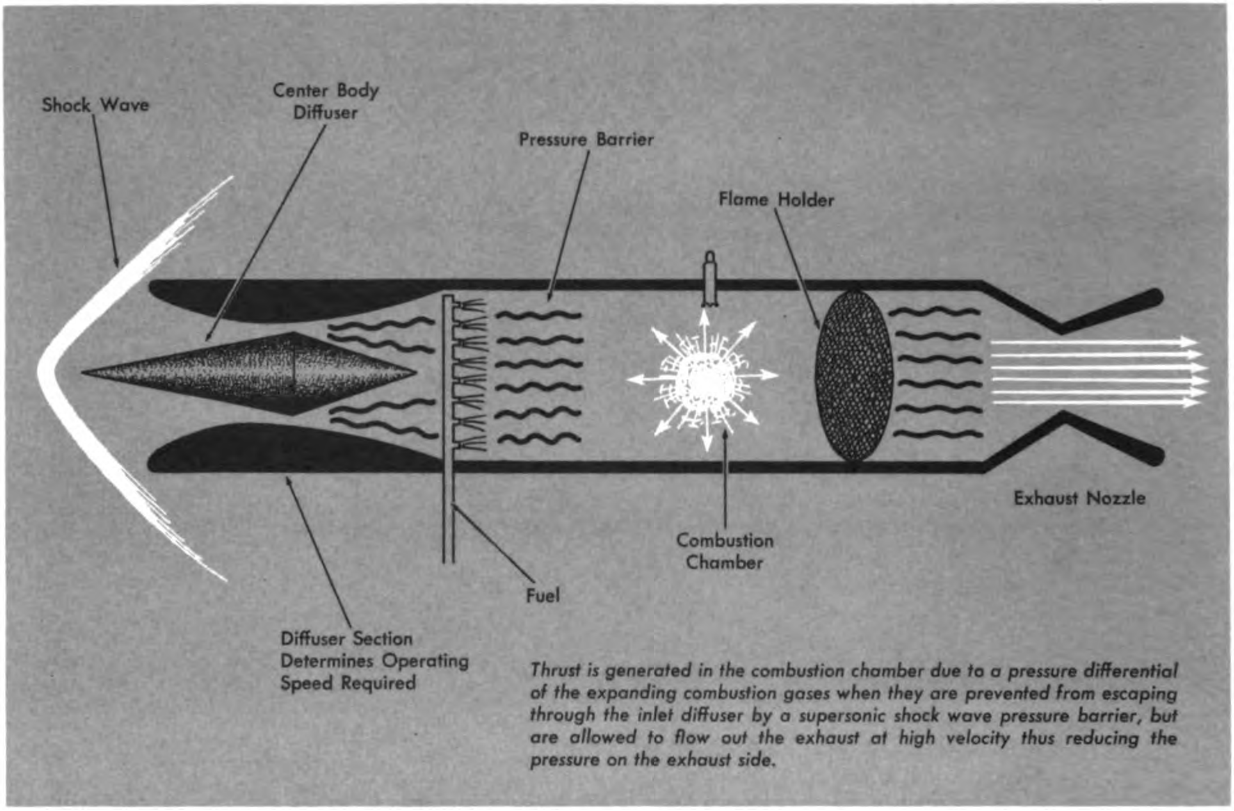
Large quantities of high-pressure and high-temperature gases are produced in the combustion chamber by the chemical reaction of a fuel and an oxidizer injected at the proper time and rate. The heat energy thus made available is converted into kinetic energy in the exhaust nozzle, or tailpipe.

Jet-propulsion systems can operate on a variety of fuels, such as kerosene, gasoline, alcohol, gunpowder, and coal dust. However, obtaining a desired result depends upon the proper choice of *fuel-oxidizer* combinations.

From the standpoint of physical state, propellants may be either *solids*, *liquids*, *gases*, or various combinations of these. Generally the propellants are either solids, liquids, or a combination of the two. Gases are rarely used because greater energy transformation results when a substance goes from the solid or liquid state to the gaseous state than results when starting with gaseous propellants and accelerating them to new velocities.

GUIDANCE

One of the most important factors in the design of an effective missile is the guidance system. Without proper guidance, the missile will never reach the target and the total effort is wasted. A guidance system must measure and evaluate flight information, correlate this with target data, and convert the results into guidance necessary to achieve the flight path to strike the target.



Thrust is generated in the combustion chamber due to a pressure differential of the expanding combustion gases when they are prevented from escaping through the inlet diffuser by a supersonic shock wave pressure barrier, but are allowed to flow out the exhaust at high velocity thus reducing the pressure on the exhaust side.

Figure 7–2. ***A Ramjet Engine***

The guidance systems of today have extended man's control of a projectile throughout its flight until impact. Before guidance systems were developed, high-speed targets (such as aircraft) could maneuver with enough agility to make fire control systems relatively inaccurate. Because of the development of guided missiles, today's defenses against manned aircraft are far more effective.

Most guidance systems are susceptible to countermeasures. To intercept a maneuvering target, a missile guidance system must be able to sense the position and course of the target and alter the missile's trajectory accordingly.

Guidance systems designed to operate against maneuvering targets must be provided with a sensing element that can keep the target under observation at all times. Sensing elements of this type are vulnerable to countermeasures. If erroneous signals are fed to the sensing element, the guidance system will cause the missile to alter its course away from the target.

Countermeasures based on this theory, combined with timely maneuvers, are one of the most effective defenses against guided missiles.

Guidance System Block Diagram

Any guidance system must employ certain components with an adequate number of stages in the system to accomplish the guidance function. The basic stages of a guidance system are shown in the diagram in figure 7–3.

The first block of the diagram, the *sensor unit block*, refers to the devices that are used in detecting various forms of mechanical and electromagnetic energy. The purpose of these devices is to translate energy into a usable form of intelligence.

From the sensor unit, the information signal is passed to the *discriminator and computer unit*, the next block in the diagram. Here the signal is "interpreted" so that it can be applied to circuits that will actuate the control surfaces. This unit can be considered as the "brains" of the missile guidance system. It makes calculations and comparisons of external and internal information at microsecond intervals to keep the missile on course.

The *reference unit* also provides inputs into the discriminator and computer unit. The function of the reference unit is to establish the conditions and refer them to the other circuitry for computation, amplification, and power conversion to the control system. To obtain a set of guidance conditions, it is often necessary to compare two sources of information. This information may come from an outside source or it may be some form of recorded information that was put into the missile prior to launch.

The guidance signals, after proper recognition, must be amplified sufficiently to become usable in the remaining units of the missile. The *amplifying block* contains circuit elements that produce "energy" for the "muscles" of the system. These amplifying devices may react to voltage, current, frequency, or combinations of these.

The "muscles" of the guidance system are represented by the *control system block.* Relays, solenoids, servo motors, and other actuating units of this block go to work, putting into operation the result of numerous calculations, comparisons, and amplifications of the initial guidance request made to the system.

The *feedback unit block,* though it may not contain any specific circuits to accomplish its purpose, must be taken up as a definite unit of the block diagram. Feedback can be thought of as that part of a guidance intelligence system which helps the system to distinguish right from wrong. It is constantly observing the guidance signals and making attempts to increase or decrease their effect so that the guidance system will have a smooth, integrated action. If any unwanted signals enter the system, it also tries to eliminate these by feeding back information signals to the previous circuits.

As the study of guidance is made, it should be kept in mind that new methods are constantly under development. It is advisable that frequent reference be made to current guidance systems progress reports.

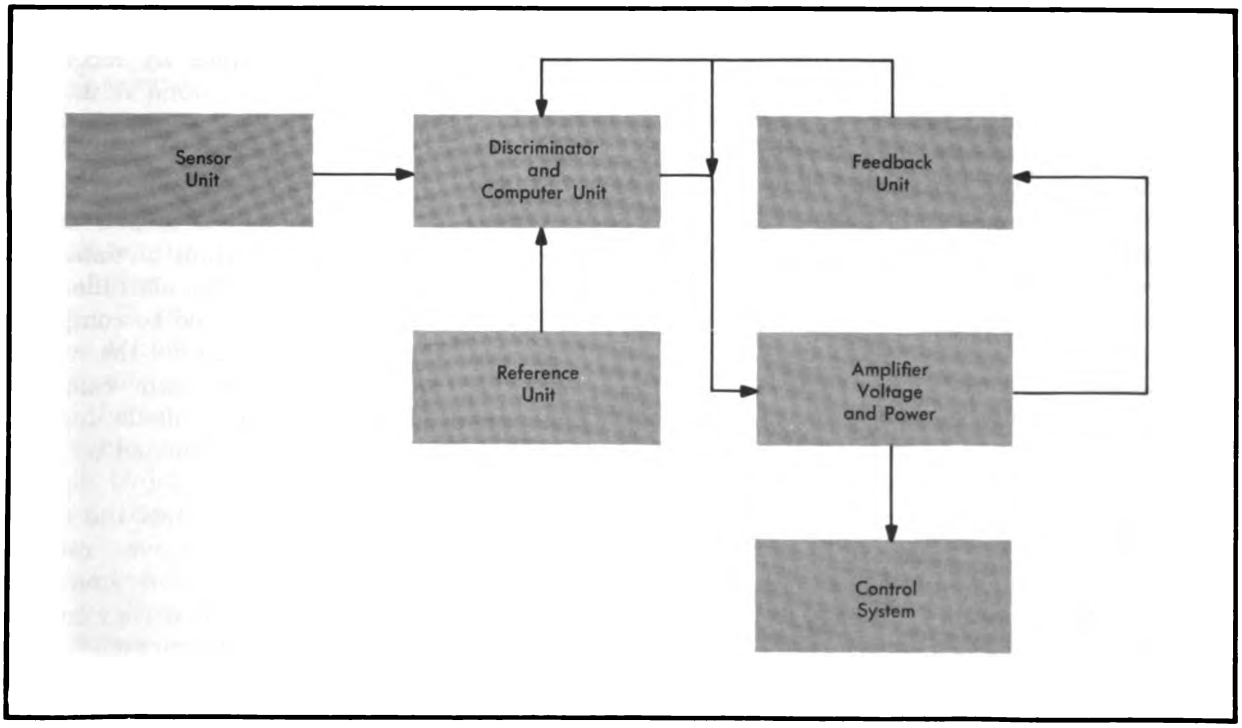


Figure 7–3. *The Basic Guidance System Block Diagram*

Methods of Guidance

To enable you to understand and appreciate the problems that may arise in defending against a specific guidance system, it is well to first have an overall picture of the various methods of guidance.

In the *preset* method of guidance, the control equipment is contained wholly within the missile. All adjustments as to course, altitude, speed, and dump-point must be made prior to the launch time. The idea of having a missile fly a predetermined path in such a manner has both advantages and disadvantages. A major advantage of such a method is that countermeasures against such a missile are quite limited; a major disadvantage is that after once launching the missile, no correction can be made for factors not previously anticipated.

In the *command* method of guidance, the intelligence for the missile's guidance comes from outside the missile. The missile contains a receiver that is capable of receiving directions from a ground station or mother aircraft and executing these commands through the control system and the control surfaces. Usually, in the command system, several channels are operated from the control station by modulating the transmitted signal at several frequencies. Changes in altitude, direction, speed, or any other factor may be made as desired by the controlling operator or programmer.

A television system may be used to give additional accuracy to this method. The controller then has a viewing point as if he were physically in the missile, guiding it to the target. The use of a television repeat-back system is limited to target areas that are not overcast.

Disadvantages of the command system are that it is generally vulnerable to jamming and lacks long range guidance capability.

When using the *beam-rider* method, a missile contains equipment which enables it to follow an electronic beam. In this method, the missile is launched to follow a radar beam to the target. The beam is directed to the target, and the missile tends to keep itself centered within the beam until it strikes the target.

The *hyperbolic method* can be used as a long- or short-range navigational network. Such a system consists of master and slave stations putting out low-frequency pulses at constant intervals. The slave station is synchronized to the master station but transmits its pulse after the master pulse. By using automatic computers contained in the missile, the missile establishes its position by comparing time differences of pulses received from the master and slave stations.

The *celestial navigation* method is highly complex. It consists of a mechanism that takes celestial fixes and, through electronic means, keeps the missile on course. This method is used primarily for long-range guidance. Its general operation is as explained in the following paragraph.

Star-tracking telescopes take a fix on some predetermined star, and the information obtained is fed to an electronic computing device that determines the position of the missile relative to the earth. Necessary controls are activated by the error voltages developed if the missile position does not coincide with the position represented by the predetermined values set into the missile.

In the method involving *terrestrial reference*, the missile position is determined through the use of charts and some characteristic property or phenomena of the earth. A system of map-matching is used. A comparison of the maps that were previously obtained by reconnaissance is made with actual ground returns received by electronic equipment contained within the missile.

Inertial guidance is an automatic navigation system using gyroscopic devices and accelerometers for the interpretation of data such as speed, position, and vehicle attitude. The outputs of these sensors are fed to computers that interpret them and guide the vehicle along a predetermined flight path. Such signals are contained within the missile and cannot be detected by radar or jammed by countermeasures.

Homing guidance systems direct the missile to the target by seeking heat waves, radio or radar echoes, or other radiation emanating from the target. This radiant energy may be generated or reflected by the target.

If the homing missile contains an illuminating transmitter and a receiver, it is an "active" homing missile. If the missile con-

tains only a receiver and depends on illumination by a remote transmitter, it is a "semi-active" homing missile. If the missile is fitted with a seeking head and depends only on the radiations from the target, it is a passive homing missile.

Sensing Elements

In the selection of a sensing unit that will detect the forms of energy that guide the missile to its target, consideration must be given to many items, some of which are:

- Maximum range
- Information required
- Accuracy
- Operating conditions
- Viewing angle of sensor
- Sensor size and weight
- Type of target
- Relative speed of target

Sensors used in missile guidance systems may be grouped according to the form of energy they detect. The two general types are mechanical and electromagnetic. The mechanical sensors respond to sound, to changes of motion, or atmospheric pressure. Examples of these are gyroscopes, accelerometers, altimeters, and sonic transducers. Electromagnetic sensors respond to RF energy (radio or radar), infrared, light, ultraviolet radiations, or the earth's magnetic field.

MECHANICAL SENSORS. The highly sensitive mechanical sensors are used to detect changes in position, attitude, and speed of a missile. Thus, by integrating such information in a computer, the missile can tell where it has been, where it is, and predict where it is going. If the predicted flight trajectory is different from the programmed trajectory, error signals are produced by the computer to cause the control system of the missile to alter its course until the missile is again on a desirable trajectory.

Using mechanical sensors, a missile can be made to follow any desired planned path and hit a fixed target with a high degree of accuracy. However, the exact path that is to be programmed into the guidance system must be known prior to launch, since there is no communication with the missile from outside sources after launch. For this reason, missiles employing mechanical sensors cannot be effectively used against maneuverable targets. Therefore, guidance systems relying solely upon mechanical sensors are seldom used for air intercept weapons. However, they are employed in air-to-ground missiles, because the target coordinates are usually fixed and are not subject to unpredictable or abrupt changes.

Mechanical systems that are sensitive to motion or changes of motion are called inertial guidance systems. Inertial guidance systems and other mechanical systems are closed systems and are not generally susceptible to jamming.

ELECTROMAGNETIC SENSORS. Sensors that respond to electromagnetic energy (including light and infrared) may be used for accurate and dynamic control of all types of missiles. Guidance may be controlled remotely (by command) or from within the missile itself (as in homing).

Electromagnetic sensors are required for tracking and guidance situations where missiles are attacking rapidly maneuvering targets (aircraft or other missiles). The guidance system for intercepting moving targets must continuously observe the motion of the target aircraft or missile. This is necessary for prediction of the aiming point or collision trajectory by the computer of the guidance system. Also, during the flight of the missile, sensors in command systems must respond constantly and rapidly to controlling signals from the guidance site.

The speed and size of modern interceptor missiles make them poor targets for conventional weapons. However, the sensitive guidance sensors required for accuracy make them vulnerable to electronic countermeasures. Since the missile reacts to the information received through its sensors, ECM can introduce false information, or masking signals, that obliterate the guidance information.

Reference Concepts in Guidance Systems

A basic principle involved in all missile systems is the concept of the reference axes. To detect direction and magnitude of an error, there must be a standard beginning point for up-down and right-left measurements so that the control system can be commanded to make

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Homing guidance systems direct the missile to the target by seeking heat waves, radio or radar echoes, or other radiation emanating from the target. This radiant energy may be generated or reflected by the target.

If the homing missile contains an illuminating transmitter and a receiver, it is an "active" homing missile. If the missile con-

tains only a receiver and depends on illumination by a remote transmitter, it is a "semi-active" homing missile. If the missile is fitted with a seeking head and depends only on the radiations from the target, it is a passive homing missile.

Sensing Elements

In the selection of a sensing unit that will detect the forms of energy that guide the missile to its target, consideration must be given to many items, some of which are:

- Maximum range
- Information required
- Accuracy
- Operating conditions
- Viewing angle of sensor
- Sensor size and weight
- Type of target
- Relative speed of target

Sensors used in missile guidance systems may be grouped according to the form of energy they detect. The two general types are mechanical and electromagnetic. The mechanical sensors respond to sound, to changes of motion, or atmospheric pressure. Examples of these are gyroscopes, accelerometers, altimeters, and sonic transducers. Electromagnetic sensors respond to RF energy (radio or radar), infrared, light, ultraviolet radiations, or the earth's magnetic field.

MECHANICAL SENSORS. The highly sensitive mechanical sensors are used to detect changes in position, attitude, and speed of a missile. Thus, by integrating such information in a computer, the missile can tell where it has been, where it is, and predict where it is going. If the predicted flight trajectory is different from the programmed trajectory, error signals are produced by the computer to cause the control system of the missile to alter its course until the missile is again on a desirable trajectory.

Using mechanical sensors, a missile can be made to follow any desired planned path and hit a fixed target with a high degree of accuracy. However, the exact path that is to be programmed into the guidance system must be known prior to launch, since there is no communication with the missile from outside sources after launch. For this reason, missiles employing mechanical sensors cannot be effectively used against maneuverable targets. Therefore, guidance systems relying solely upon mechanical sensors are seldom used for air intercept weapons. However, they are employed in air-to-ground missiles, because the target coordinates are usually fixed and are not subject to unpredictable or abrupt changes.

Mechanical systems that are sensitive to motion or changes of motion are called inertial guidance systems. Inertial guidance systems and other mechanical systems are closed systems and are not generally susceptible to jamming.

ELECTROMAGNETIC SENSORS. Sensors that respond to electromagnetic energy (including light and infrared) may be used for accurate and dynamic control of all types of missiles. Guidance may be controlled remotely (by command) or from within the missile itself (as in homing).

Electromagnetic sensors are required for tracking and guidance situations where missiles are attacking rapidly maneuvering targets (aircraft or other missiles). The guidance system for intercepting moving targets must continuously observe the motion of the target aircraft or missile. This is necessary for prediction of the aiming point or collision trajectory by the computer of the guidance system. Also, during the flight of the missile, sensors in command systems must respond constantly and rapidly to controlling signals from the guidance site.

The speed and size of modern interceptor missiles make them poor targets for conventional weapons. However, the sensitive guidance sensors required for accuracy make them vulnerable to electronic countermeasures. Since the missile reacts to the information received through its sensors, ECM can introduce false information, or masking signals, that obliterate the guidance information.

Reference Concepts in Guidance Systems

A basic principle involved in all missile systems is the concept of the reference axes. To detect direction and magnitude of an error, there must be a standard beginning point for up-down and right-left measurements so that the control system can be commanded to make

Methods of Guidance

To enable you to understand and appreciate the problems that may arise in defending against a specific guidance system, it is well to first have an overall picture of the various methods of guidance.

In the *preset* method of guidance, the control equipment is contained wholly within the missile. All adjustments as to course, altitude, speed, and dump-point must be made prior to the launch time. The idea of having a missile fly a predetermined path in such a manner has both advantages and disadvantages. A major advantage of such a method is that countermeasures against such a missile are quite limited; a major disadvantage is that after once launching the missile, no correction can be made for factors not previously anticipated.

In the *command* method of guidance, the intelligence for the missile's guidance comes from outside the missile. The missile contains a receiver that is capable of receiving directions from a ground station or mother aircraft and executing these commands through the control system and the control surfaces. Usually, in the command system, several channels are operated from the control station by modulating the transmitted signal at several frequencies. Changes in altitude, direction, speed, or any other factor may be made as desired by the controlling operator or programmer.

A television system may be used to give additional accuracy to this method. The controller then has a viewing point as if he were physically in the missile, guiding it to the target. The use of a television repeat-back system is limited to target areas that are not overcast.

Disadvantages of the command system are that it is generally vulnerable to jamming and lacks long range guidance capability.

When using the *beam-rider* method, a missile contains equipment which enables it to follow an electronic beam. In this method, the missile is launched to follow a radar beam to the target. The beam is directed to the target, and the missile tends to keep itself centered within the beam until it strikes the target.

The *hyperbolic method* can be used as a long- or short-range navigational network. Such a system consists of master and slave stations putting out low-frequency pulses at constant intervals. The slave station is synchronized to the master station but transmits its pulse after the master pulse. By using automatic computers contained in the missile, the missile establishes its position by comparing time differences of pulses received from the master and slave stations.

The *celestial navigation* method is highly complex. It consists of a mechanism that takes celestial fixes and, through electronic means, keeps the missile on course. This method is used primarily for long-range guidance. Its general operation is as explained in the following paragraph.

Star-tracking telescopes take a fix on some predetermined star, and the information obtained is fed to an electronic computing device that determines the position of the missile relative to the earth. Necessary controls are activated by the error voltages developed if the missile position does not coincide with the position represented by the predetermined values set into the missile.

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A basic principle involved in all missile systems is the concept of the reference axes. To detect direction and magnitude of an error, there must be a standard beginning point for up-down and right-left measurements so that the control system can be commanded to make

the proper corrections. This standard becomes quite complicated as the complexity of the guidance system increases, especially for the complex system of long-range missiles.

A reference system can be based on an actual arrangement of physical components, or it can be quite arbitrary. For such an arrangement of physical components, the homing-type missile could be cited as an example. The reference for such a system is the physical and corresponding electrical orientation of the antenna.

In the homing missile, with a fixed antenna that looks directly forward, the arrangement is easily analyzed. Note in figure 7–4, which shows the effect of attitude on missile reference, that what is *up* to the antenna is *up* to the missile. Whether the attitude is inverted or proper, the command resulting from the error signal detected at the antenna serves to turn the missile toward the target.

In the initial planning of a flight, it is necessary to be exact about the primary reference of the trajectory coordinates. The selection of these coordinates in an inertial system is a rather arbitrary decision because the earth is pursuing its orbit about the sun and rotating about its own axis. The requirement, then, that the reference be stable or fixed in respect to the guidance system is not directly available.

Since a gyroscope wheel maintains rigidity in space or, more scientifically, in inertial space, this inertial space becomes the reference. As far as inertial space is concerned, the reference is a particular direction, usually with the axis of the gyro parallel or perpendicular to the force of gravity at the time and place of launching of the missile containing the gyro.

GUIDANCE COORDINATES. The simplest concept of guidance coordinates is the set already mentioned in which a seeking head is fixed to a missile so that its seeing axis is only to the front along the projected line of missile travel.

The seeker head is orientated so that the signals going from its detector to the control system institute control movements that place the missile back on a path directed toward the target. When the missile rolls or changes attitude, the guidance form changes its attitude accordingly. Therefore, the guidance reference is fixed to the missile in the fashion shown

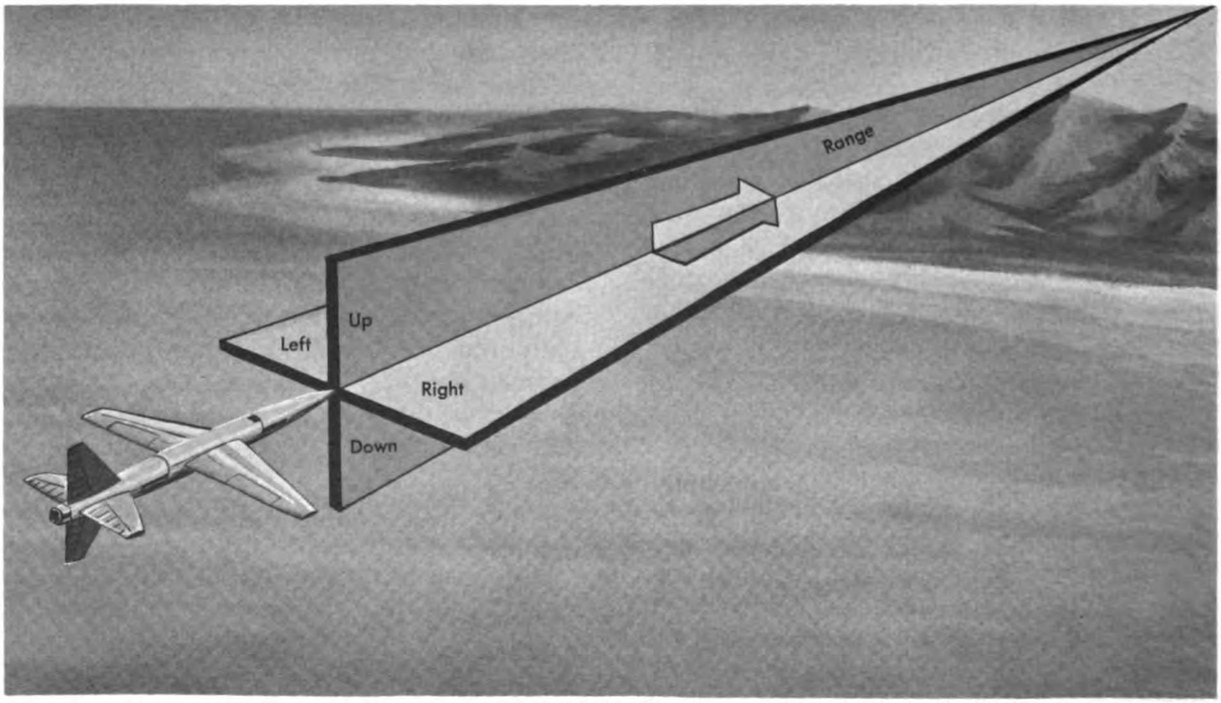

Figure 7–4. *Simple Guidance Coordinates*

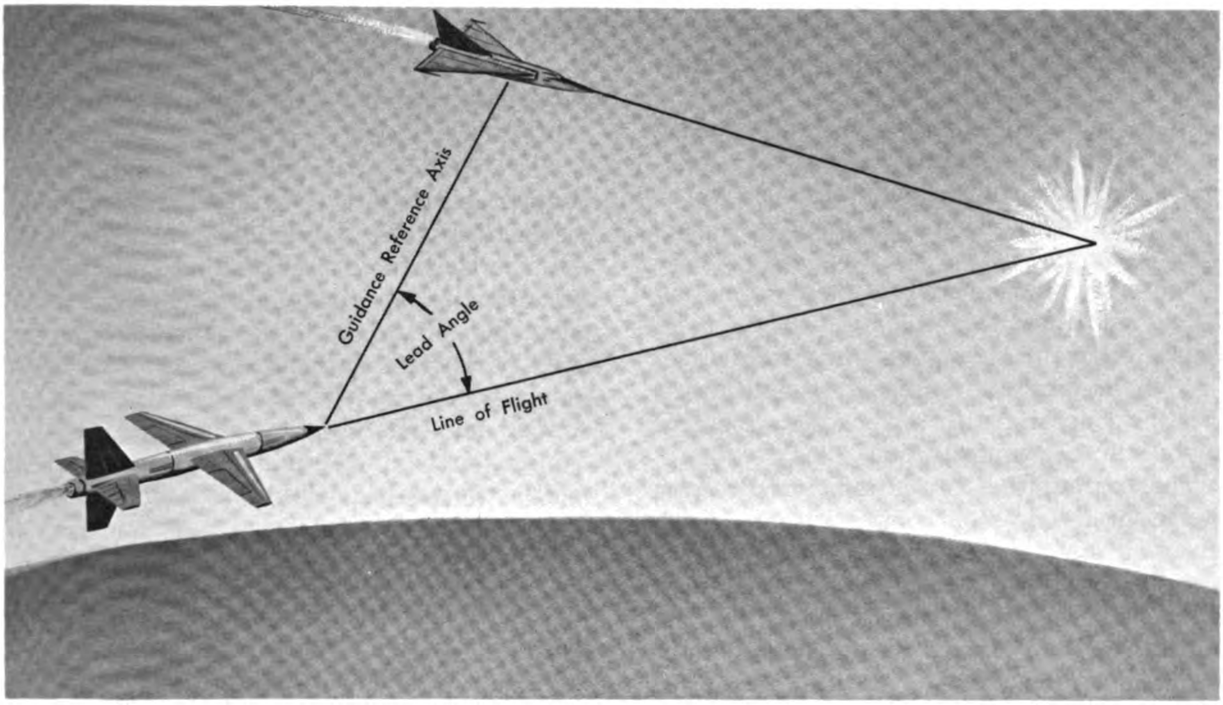

Figure 7–5. *Variable Guidance Reference*

in figure 7–4. The guidance reference moves with the missile so that there is no confusion as to movement required to correct any error signal.

This could be termed a two-dimensional reference system since only up-down and right-left signals are detected. The range dimension may or may not be a function of the guidance equipment. In some cases, range is an ordinance function only necessary for warhead detonation; it has no direct use in guidance in such cases.

In later developments, the seeker head has been mounted onto a missile by a universal joint (gimballed) arrangement. With such an arrangement, the seeker can look at a moving target while the missile course is projected at a lead angle or collision course. The course is designed to make contact with the target with a minimum of maneuvering required by the missile. The missile "looks over its shoulder," as shown in figure 7–5, and the error signals thus received are properly interpreted to the control system so that a correct collision course can be maintained.

According to geometry, two intersecting lines determine a plane. Thus, the problem could be considered two dimensional if the lines were ideally straight. The problem is made complicated, however, by the lead angle involved, requiring manipulation of the guidance signal according to trigonometric functions. The reference is still fixed to the missile but is transformed or interpreted from the antenna signal. The antenna signal is in the guidance reference to the control-system signal which actuates the missile properly.

TRANSFORMATION OF AXES. Just about all missile guidance systems perform transformation of a reference system to the axes of the control system. In some systems there are several of these transformations. In the system just outlined, the reference axes are rotated through an angle to make them correspond to the control reference. Rotation of axes is a means of transformation.

It is important to remember that when a transformation is performed on a system of axes or a coordinate system, the effect is on all three axes. If there are two boxes, you place one box next to the box which is the standard to compare for size. To do this, you have moved the box. Moving a set of axes for comparison with a standard is called translation of the axes. Thus, transformation of a reference system can involve both rotation and translation.

That a missile performs such an operation is not often obvious from reference to schematic diagrams, but such a function is the reason for many complications in the electronics equipment.

Not every missile performs a transformation of its error signal to develop the control command. Some missile systems detect the direction of the error, determine the amplitude of the signal necessary to correct the error, and apply it to the controls.

The computation of the amount of error signal for use by the control system is not always a direct result of the concept of reference coordinates, but such a conception does enter in. Almost all missile systems make some attempt to distinguish the magnitude of error so a proportionate amount of control can be applied, thus the term *proportional control.*

Externally controlled missiles require a further consideration. Such missiles have an ideal trajectory charted for them in space and are then commanded to stay on it. Either the flight path or the command is actually instituted by some means external to the missile. Remote radio control is an example of external control.

The tracking information for the remote control is by visual, optical, or electronic means. Both the beam rider type of missile and the long-range electronic navigation system utilize charted or projected paths of radio energy to guide them to their target. The desired course then is the prime axis of the reference system, and the missile is controlled so that it does not deviate.

Missile Trajectories

Missile trajectories follow many types of curves. For example, the *hyperbolic course* is an exactly predicted path that is laid out by a loran-type system.

PURSUIT CURVE TRAJECTORY. The principle of the fixed seeker head in the homing missile has already been introduced. The seeker head is fixed to the missile. It processes the error signal in relation to its axis and the missile's axis, inasmuch as the missile airframe and seeker axes are common.

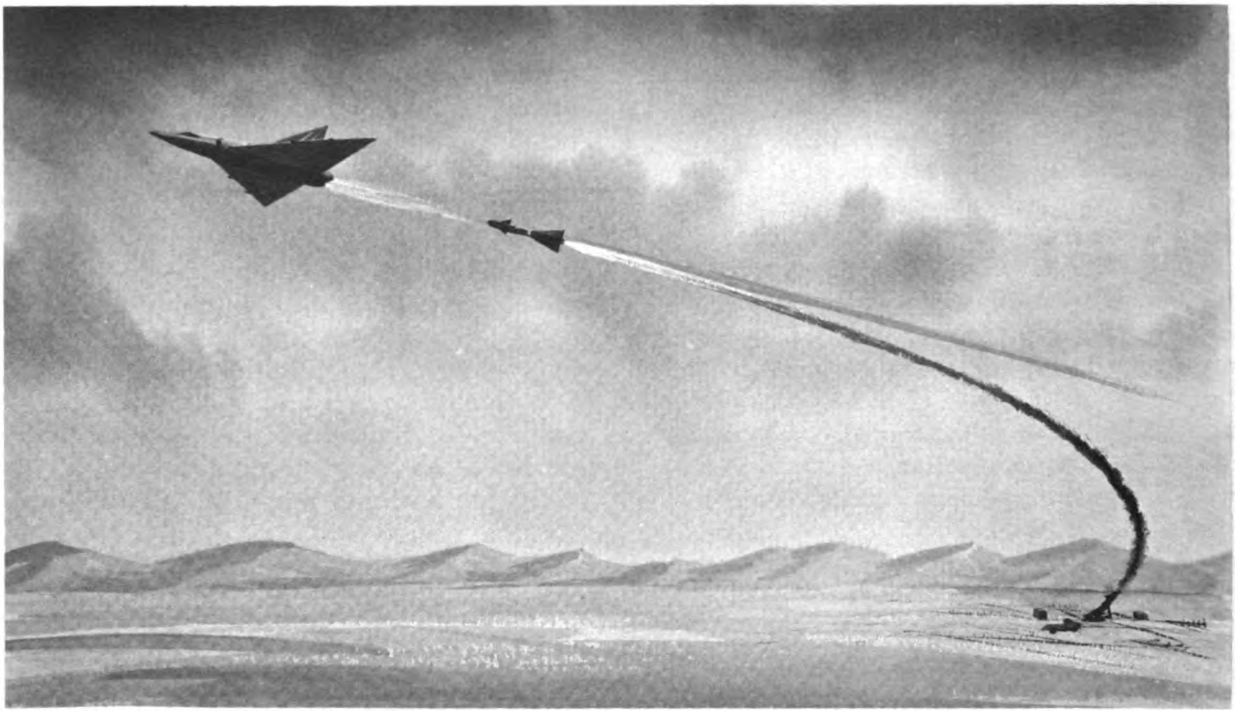

Figure 7–6. ***Pursuit Curve Trajectory***

The trajectory is a pursuit curve as shown in figure 7–6. Note that in the pursuit curve of the surface-to-air missile, the sharper curvature occurs toward the end of the flight. The majority of the flight is under gliding or coasting conditions because the rocket motor thrust lasts only a small portion of the flight. At the end of the flight when the greatest requirement for turning occurs, the missile has the least capability for turning. The possible turn required of the missile could conceivably be beyond the areodynamic limits of the missile.

Lead-Angle Trajectory. The drawbacks to pursuit-type homing can be overcome by swiveling the seeker head in its mount so that it can look in directions other than that in which the missile is going.

The trajectory flown by such a missile is known as the collision course or a lead angle course. Notice in figure 7–7 that this course approximates a straight line, thus subjecting the missile to a minimum of maneuvering. If the angle between the seeker axis and missile axis remains fixed, the missile will intercept the target. The fact that this angle stays constant when both target and missile are in motion compensates automatically for any differences in speed between the two.

The representation of such a problem can best be done by vectors where the magnitude of speed is also taken into account. The diagram in figure 7–7 represents the results of such a development. A slight curve in the trajectory is caused by the deceleration of the missile after burn-out.

Beam-Rider Trajectory. The beam rider's course is a result of following or riding the controlling radar beam. A tracking radar feeds information to a computer to predict the position at which the missile can intercept the target. A second radar generates the beam for the missile to ride a collision course to the target.

Artillery-Type Trajectory. A parabolic trajectory is the classic curve accepted for a surface-to-surface missile in free flight and is referred to as an artillery-type trajectory. But now, if by extending that same free flight until the missile no longer returns to the earth but becomes a satellite traveling about the earth, the trajectory is known as an ellipse, as are all solar system orbits.

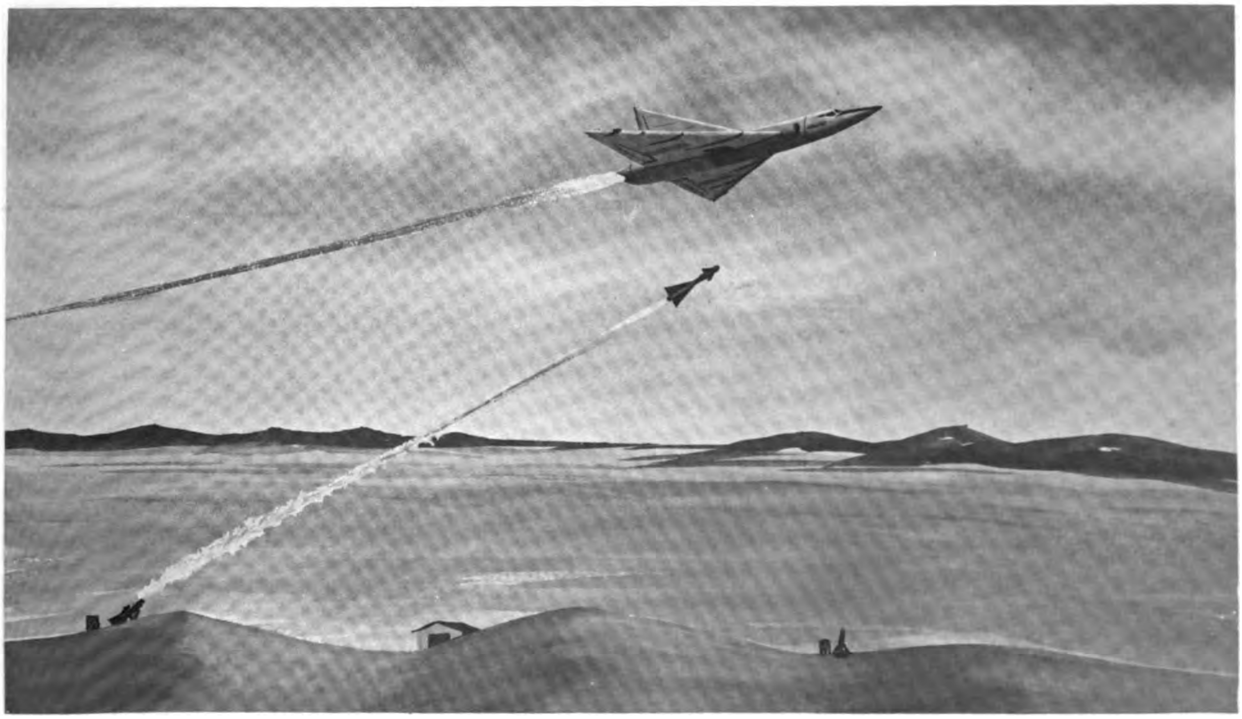

Figure 7–7. *Lead Angle Interception*

In surface-to-surface missiles, there are several possible trajectories. The choice of trajectories is made before the missile is designed. Once built, a missile is limited to flying the trajectory for which it was designed.

Rocket Trajectory. The rocket trajectory is similar to the artillery trajectory. However, the difference of definition lies in the vertical launch angle of the rocket. Note in figure 7–8 that the rocket is launched straight up until it clears the impeding portions of the atmosphere and is then precessed or tilted to an angle designed to give the proper range.

Greater range from a rocket flight can be accomplished by adding wings to the rocket. The modified trajectory obtained under such conditions is shown in figure 7–9.

The first portion of the rocket flight through burn-out time and over the peak of the trajectory is the same as before. In gliding down the trajectory, the winged rocket enters the portion of the atmosphere which is of sufficient density for the wings to exert a lift. This lift causes the rocket's trajectory to be extended as indicated in the illustration.

Flat Trajectory. A flat trajectory is the type employed by aircraft and some surface-to-surface missiles. After the launch phase, the missile maintains a constant midcourse altitude at the level best suited to the propulsion means employed. Turbojets or ramjets can serve to drive a missile at supersonic speed in this region.

AIR-TO-AIR MISSILES

The elementary air-to-air guidance system may employ homing principles or it may be a modified system of command guidance, such as a beam rider. However, homing guidance offers many advantages to an intercept pilot in a combat situation. The complexity and swiftness of the attack leave him with very little time to spare for sending command signals, even when this is automatically accomplished by a computer.

Homing systems are self-controlling, only requiring that the guidance circuits be locked on the target to begin active control. They may operate on any form of energy that is propagated, such as waves or vibrations; however, electromagnetic energy is the only suitable energy at air-to-air missile speeds.

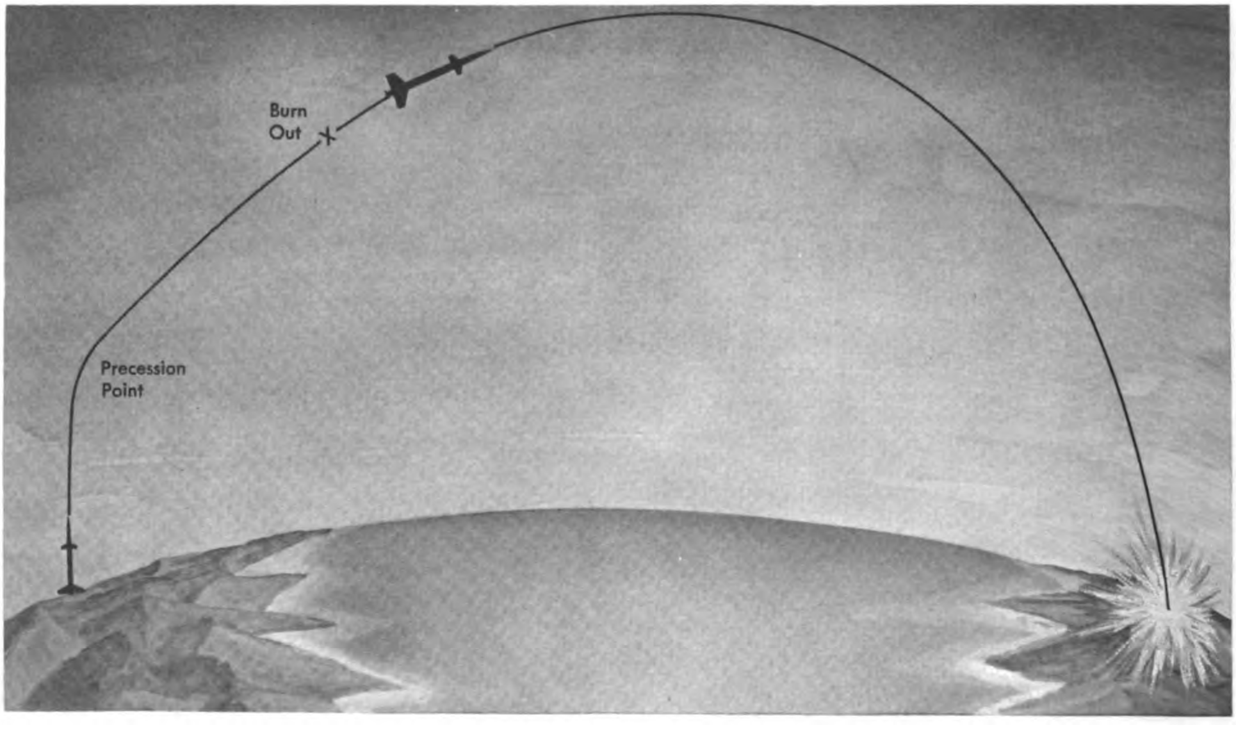

Figure 7–8. *High-Angle Rocket Trajectory*

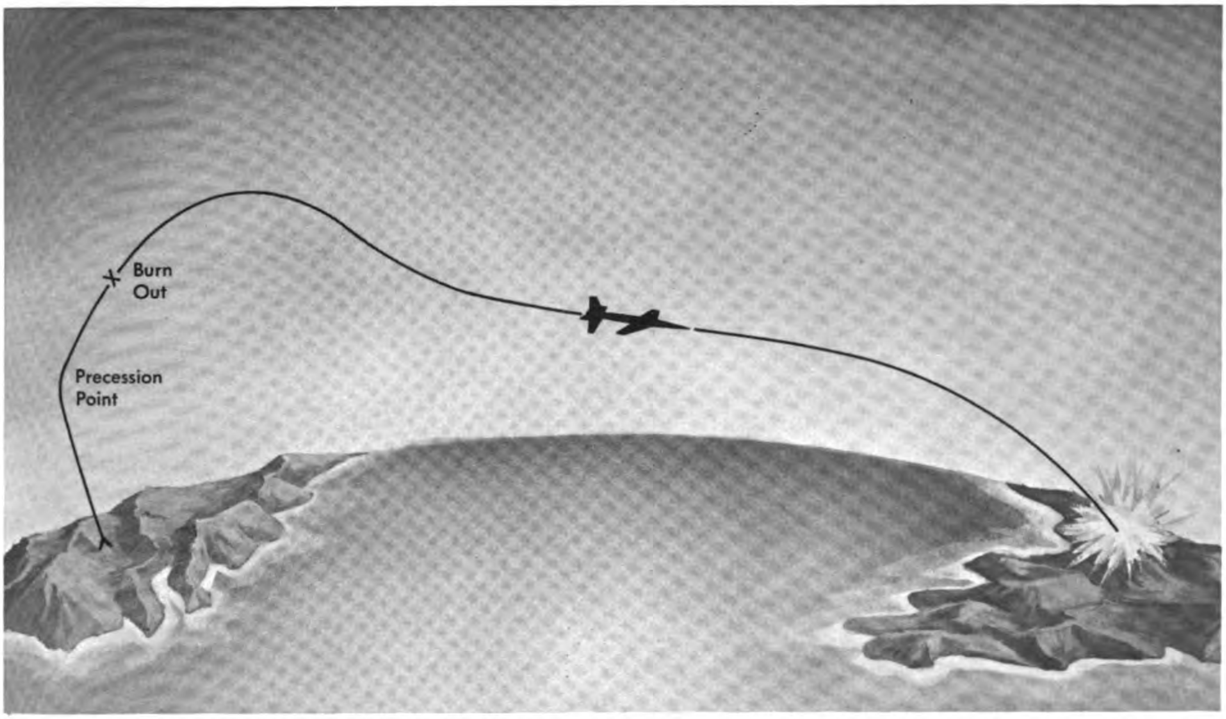

Figure 7–9. *Winged Rocket Trajectory*

Passive Seekers

The primary sources of radiant energy which air-to-air homing missiles seek are RF sources (radio and radar) and IR from the engine exhaust or skin heat. Infrared has the maximum reliability in terms of the emission source. IR source homing systems are ideally applicable to many air combat situations.

Infrared seeking missiles are inherently smaller, lighter, and simpler in construction than RF types. The simplicity of design of an infrared seeking missile is shown in figure 7–10. The system shown utilizes a bolometer.

The infrared seeking system has outstanding tactical and physical characteristics. The launching of IR seeking missiles allow the maximum rate of fire. All that is required of the fire control radar is that it enable the seeker to locate and lock-on the source (target) of the radiant energy. Once the infrared seeker is launched, it generates its own guidance signals, requiring no more information from the fire control radar. This allows the fire control radar to begin tracking another target without delay.

RF seekers are well suited for destruction of radar and communication sites and vehicles carrying radar. RF energy sources make excellent targets for homing devices but are not always dependable. RF sources are usually man-made and are readily controlled. Radio silence becomes a simple and effective countermeasure against RF seekers.

Active Seekers

Active-homing guidance systems contain both the source of the radiating energy for illuminating the target and the receiver for detection of the reflected energy from the target. This system is self-contained, requiring nothing from the interceptor once it is fired and locked on the target.

The elementary active guidance system consists of a transmitter, receiver for the detecting of the target, a computer for predicting the track of the target, and control surfaces that respond to the computer output. Basic types of radar that may be used in active-homing guidance systems include pulse and CW types.

A major problem of a radar tracking device is selecting or separating the desired target from the background noise or other nearby targets (target discrimination). This problem is critical in the homing system. If return

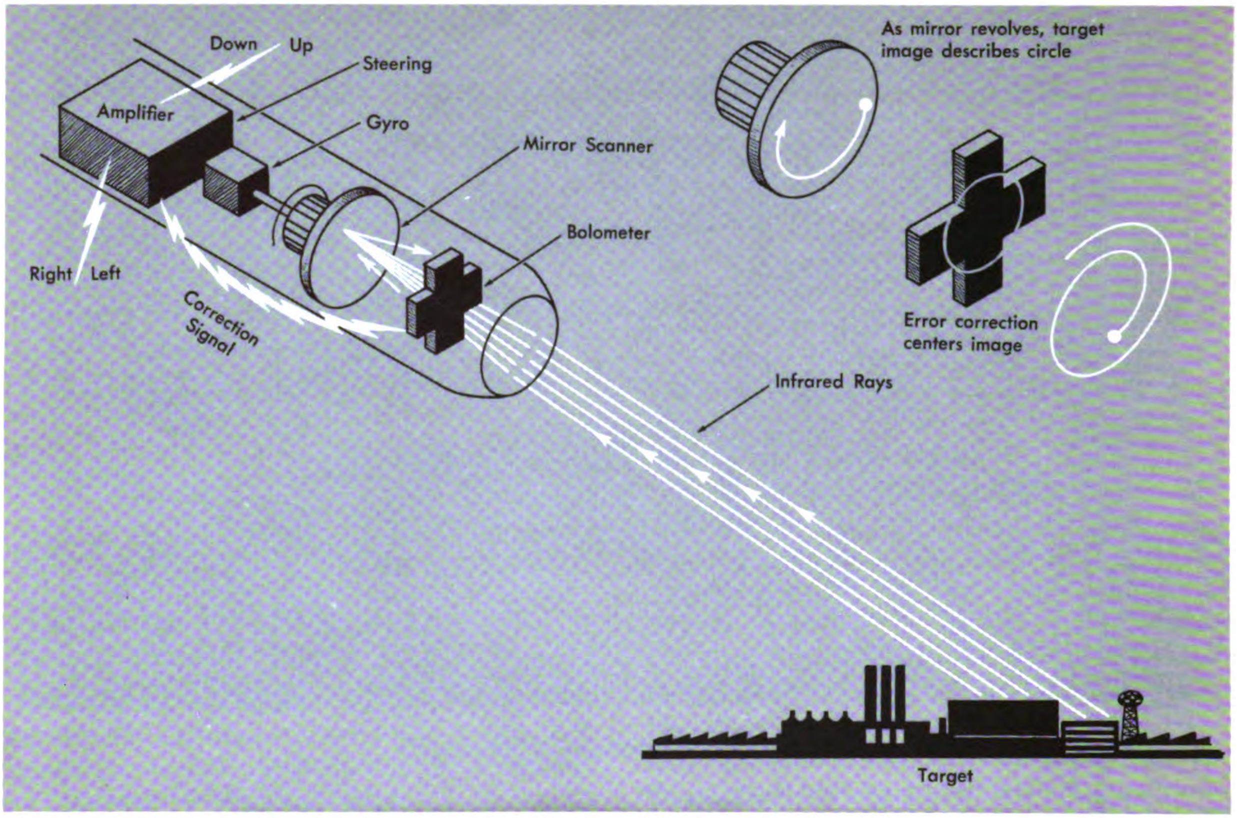

Figure 7–10. *IR Seeker*

echoes are at different ranges but along the beam axis, the guidance system will try to home on either return unless one is eliminated as an undesirable target.

The selection of the desired target may be accomplished by gating to range or velocity. If the range gate of the homing radar is slaved to the fire control radar until launching, it will be locked on the desired target, eliminating much of the background clutter and undesired targets.

The ability of the homing radar in the missile to resolve targets at the same range and velocity is dependent on the beam width. Errors resulting from electrical noise and maneuvers of fast-flying aircraft, along with interference from other sources, are reduced by a memory unit that will remember the track of the target and will not respond to rapid transient signals or momentary sporadic noise signals.

The range gate and tracking memory circuits respond to signals from the target and are susceptible to generating errors within the missile's guidance system. From the viewpoint of the DSO, these are prime targets for electronic countermeasures. If the range gate loses the target for any extended period of time, the chances of recovering the target are poor. If the target makes unexpected maneuvers during the time the missile has lost the target, the chances of the target escaping are very good.

Another weakness of active-homing guidance systems is their range. The air-to-air missile must be small if it is to be carried on an interceptor. This means that antenna size must be kept small, severely limiting antenna gain. The power required for long-range operation requires large and heavy components. The range of the radar for an active radar-homing missile will be short for effective guidance. Active radar-homing systems lend themselves to terminal guidance.

Air-to-Air Lock-On Techniques

There are at least three ways that an air-to-air missile may be locked-on its intended target.

An *optical sight* may be used for locking-on a target by slaving the antenna of the missiles radar to the optical sight. When the missile is activated, the range gate searches until the target is found and locked-on (gated). The pilot determines if the missile system has selected the proper target.

The *missile radar* may be made to automatically search for and lock-on a target. The information from the missile can be displayed on an indicator for the pilot who will determine if the correct target has been gated.

The *interceptor radar* can be locked with the missile radar. The larger radar of the interceptor will be capable of greater range than the missile radar or the optical system. It will not be overly handicapped by fog or poor visibility due to inclement weather as are the optical systems. The interceptor radar fire control system may be fitted with a computer that receives the video and tracking information and computes a fire control solution. The pilot will fly the interceptor to the computed heading and launch the missile. He must fly the interceptor along the attack heading until the missile has acquired the target or has a high probability of acquiring the target.

Saturation of Seekers

Homing missiles guidance systems are subject to saturation when launched in the proximity of a powerful transmitter or as it approaches the target. This saturation could be strong enough to limit or even nullify the guidance functions of the system.

Radar equipment may have several effects from saturation: AGC may cease to function; the sensitive crystal detector may be damaged; or multiple reflections may be strong enough to produce incoherent signals, causing the guidance system to become confused. Multiple reflections may occur at the target or from background clutter such as clouds or the surface of the earth.

Infrared seekers are affected when the sensitive bolometer or photoconductive cell is damaged by excessive radiation. Sources of heat that may blind an infrared detector are the sun or possibly an atomic explosion.

Missile miss distance under saturation (blinding) conditions depends on how far the missile is from the target at the time guidance is lost. Missile designers use several techniques to reduce the effects of saturation. Radomes may be designed to have filtering characteristics that reduce the energy having undesirable wavelengths. Discriminating circuits are used to reduce noise. Some missiles have circuits that protect against the powerful radiations during launching. These circuits may actually deactivate the seeker until the missile is at a safe distance from the launcher.

Air-to-Air Intercept Order of Events

Air defense may be considered as a series system. The steps necessary for a successful aircraft interception begin with detection of the target, and continue through tracking and vectoring to the actual firing and detonation of the weapons. Each step also has a definite time relation and sequence to the others. If any step in this series of events is not completed, the following steps cannot be accomplished effectively.

Countermeasures of modern defense weapons are planned and executed on the above premise. The vulnerability of each link in the intercept chain of events may be exploited to break the chain and penetrate the system. Understanding the series of events resulting in AI is vital to the DSO.

EARLY WARNING. The target must be detected, located, and identified by the early warning system (usually radar) in sufficient time to alert interceptors and vector them to the intercept area. It is reasonable to assume that the interceptors are either already airborne or in a state of readiness enabling them to take off on a moment's notice.

VECTORING. The direction and speed of the target are determined by the early warning system and then the interceptor is guided along a course that will bring the interceptor into contact with the target. This technique is often referred to as "vectoring." If the interceptor is an all-weather type, it may be assumed that it is fitted with radar for detection of the target. The range of the airborne radar is relatively short; consequently, the interceptor must be controlled from the early warning radar until it is within search range of the interceptor's radar.

INTERCEPTION. Airborne interception (AI) is made when the interceptor has made contact with the target; that is, when the airborne search radar has the target displayed and identified. The volume of space that the airborne radar must search is determined by the accuracy of the vectoring information. The speed and possible maneuver of a modern aircraft make the time element of an AI critical. The success of the intercept often depends on the accuracy of the vectoring information.

RADAR TRACKING. The mission of the interceptor pilot is not complete upon contact with the target. In order to use his weapons properly, he must observe the target's position and motion. If the interceptor is a night fighter, he must use his radar in a tracking mode, since it is reasonable to assume he will not observe the target visually.

If the above steps have been completed successfully, then all that remains to be done by the interceptor pilot is to place the interceptor in the best position for firing the missile. He will usually do this in a manner that gives him the best chance of survival.

Summary of Air-to-Air Missiles

The type of missile guidance employed depends on many factors. The missile may or may not be guided from the interceptor. If it is guided, chances are that it will not be of a command-guidance type. There are at least two reasons for this. The percent of kills cannot be increased by salvos, since command-guidance systems can only control one missile at a time.

Another factor is that the target and the missile must be kept under surveillance as directions are transmitted to the missile. This increases the operator complexity. Homing-type missiles do not have these problems and therefore are more desirable than command guidance for AI units.

Active type homing systems are less desirable for air-to-air purposes, since such systems require that the missile carry a transmitter, thereby increasing the weight and size of the missile. The semiactive and passive homing types are more desirable, since they do not require a transmitter and therefore may be much smaller and lighter, increasing their range and maneuverability.

These lighter and smaller homing missiles require different firing techniques. The passive type allows the interceptor to break away from the attack as soon as the salvo has been fired. The semiactive homing type requires that the interceptor radar continue to illuminate the target with its radar until the missile has reached the target.

Another factor to be considered is the reliability of the missile guidance. Passive homing systems depend on the target radiation for guidance. This radiant energy may be radio frequency energy from electronic equipment or infrared energy from the heat of the engines. The first may be controlled from within the target and therefore is somewhat unreliable. The heat of the engine, however, is not so easily controlled. The greatest problem with heat seekers is that inclement weather and clouds affect their range.

The important point to remember relative to the use of guided missiles is that each system has certain characteristics built into it that give it an advantage under some tactical conditions and disadvantages for other conditions. The DSO must be familiar with these system limitations in order that he may make the best plans and perform with maximum effectiveness against these systems.

Another extremely significant point in the above discussion is that an airborne intercept sequence is a series system. The success of the system requires that each step be completed successfully. The active defensive series of events therefore begins with detection of the bomber and progresses through the series of events to the firing of the weapons. If the DSO can prevent completion of any of the above air defense actions, he improves his chances of survival and his chances of penetrating an enemy defense system.

Defensive countermeasures against AI begin when the attacking bomber first enters the defensive net. Techniques for countering the enemy electronic systems are numerous and may include any form of confusion or evasive action that the DSO has at his disposal, within the prescribed operations plan. These techniques may include forms of mechanical and electronic jamming, decoys, maneuvers, or even destruction of the sites.

Any delay in the detection and observation of the bombers flight path by enemy radar may mean the difference between success or failure of the mission.

SURFACE-TO-AIR MISSILES

The role of the interceptor aircraft is eliminated in the launching of surface-to-air missiles. The steps that are necessary in the launching of a surface-to-air missile are fewer, but again involve detection and guidance equipment that is vulnerable to countermeasures.

Countering SAM

Any degradation of the early detection system is favorable to the attacking aircraft. The attacking bomber must be destroyed before it can release its weapons in order to prevent the success of its mission. The guidance radar for the surface-to-air missiles (SAM) needs accurate coordinates to insure a quick lock-on and track capability. Time is of major importance in an attack against high performance aircraft with stand-off weapons.

Techniques employed by the DSO against a surface-to-air missile installation begin with the EW radar and may be jamming of any type, decoys, destruction, or maneuvers. Combinations of these techniques improve effectiveness. Once the early warning line has been penetrated, he must be alert for the tracking radar.

The tracking radar is required for accurate and continuous information of the bomber's position. Interference (noise) of any type has an adverse effect on the accuracy of the information a tracking radar produces and thereby increases the chances of the attacking bomber completing its mission.

Guidance for SAM

Surface-to-air missiles do not have the extremely severe limitations of size and weight that are imposed in air-to-air operations. Guidance systems may employ heavy, long-range, multiple radar or radio link installations. Several stations are feasible. The following discussion describes the functions of surface-to-air guidance system components.

RADIO COMMAND SAM. Figure 7–11 illustrates the major components of a surface-to-air command guidance system.

The brain of the system is the computer. Sensing equipment includes the radars that provide inputs to the computer and the missile receiver for receiving commands. The inputs to the computer are the target position information from the target tracking radar and the missile coordinates from the missile tracking radar. The outputs of the computer point the launcher, signal the moment to fire, and provide guidance information for the correction of the missile's flight path until it reaches a point where the detonation of its warhead will destroy the target. The computer may generate a signal that will fire the warhead, or the missile may contain proximity detonators.

Surface-to-air missiles may also be guided in their final phases of flight (terminal phase) by passive or active homing systems.

The information for pointing the launcher is based on the input from the target tracking radar. After the missile has been launched, the tracking radar continues to gather target position information for the computer input. This data provides continuous correction of the predicted path of the target.

The input from the missile tracking radar is continuously checked by the computer to determine if the missile is maintaining a collision course. The output difference of the desired and the actual course are interpreted by the computer and converted into guidance signals for corrections of the missile flight path. These corrections are transmitted to the missile as coded messages by way of the command radio link, as shown in figure 7–11.

The optimum path may or may not be the shortest path to the target. Some missiles ascend vertically to their operating altitude and then, after the boost phase is completed, they are commanded to turn toward the target intercept point. Other missiles may take the shortest path to the target in order to reach the target in minimum time.

The geometry of the missile path is only limited by the capabilities of the missile (e.g.,

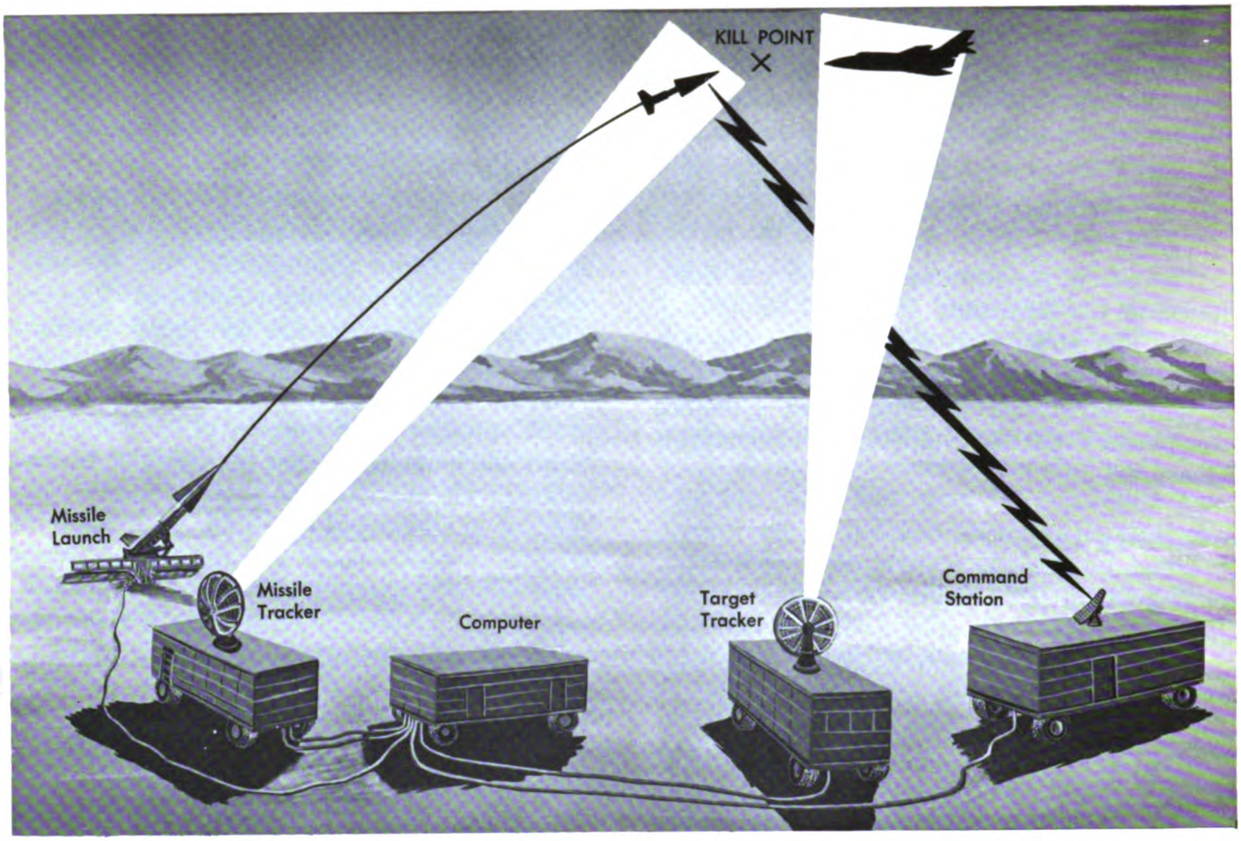

Figure 7–11. *Surface-to-Air Command Guidance*

the degree of maneuverability, range, speed, or operational altitude requirements).

BEAM-RIDER SAM. The normal trajectory of the beam-rider missile is along the center of a radar beam. Guidance is accomplished by pointing the beam in the desired direction. This is a form of command guidance, since the missile may be directed to fly a desired path from the launching site.

The missile tracking beam doubles as controlling link and missile flight monitoring. The missile contains sensing elements that determine the position of the missile relative to the beam axis. The outputs of the sensing elements are amplified and fed to control elements that alter the course of the missile toward the center of the beam.

Once the missile is captured by the beam, it will continuously seek the center of the beam. The beam is directed to a point of impact calculated by the computer, and corrections are accomplished, as errors are detected by the computer, by moving the beam in the desired direction.

Sources of errors in beam-riding missiles are external noise (possibly jamming), failure of the beam to point in the desired direction, possible mechanical jitter, or failure of the missile to remain on the beam axis due to aerodynamic limitations.

SAM Intercept Series of Events

The surface-to-air missiles are vulnerable to electronic countermeasures. Inspection of the series of events necessary for a successful surface-to-air missile attack suggests countermeasures techniques against such attacks.

The missiles launching and guidance systems require prelaunch information. The tracking radars are usually designed to search limited sectors and would consume valuable time if they were required to search the total area about the missile site for the target. Therefore, general information from the early warning sites, including bearing and height information, must be fed to the missile system.

The sequence of events for a surface-to-air missile attack begin with the first detection of the attacking vehicle by the early warning system. The early warning station determines the identity of the object and notifies operations control. It also provides the tracking radars with position information.

Upon being alerted, the missile and the launcher are prepared for firing. When the target (penetrating bomber or missile) is within range, the missile is launched and guided to the target.

COUNTERMEASURES FOR MISSILES

Countermeasures techniques employed against the missile may begin with jamming (mechanical and electronic) of the early warning radar. The purpose of this action is to delay the enemy's acquiring tracking and target size information.

Maneuvers may be employed to prevent early detection. Decoys may be employed in the hope of confusing the radar observer. Diversionary attacks may aid in the confusion of the defensive net.

If the attacking bomber has penetrated within range of a tracking radar, jamming could be used effectively again but the purpose has changed.

Jamming of the tracking radar, while trying to mask the true flight path of the penetrating vehicle, attempts to introduce (deliberately) errors in the tracking circuits of the radar. This may be accomplished by the use of chaff in bursts, specialized forms of jamming, decoys for leading the tracking radar off the target, or planned maneuvers.

Obviously, the more knowledge that the DSO has of the enemies' equipment (employment and deployment), the more successful he will be in the performance of his duty.

The techniques discussed above are not the only efforts that result in more effective bomber defense techniques. Continuous training and planning are necessary requirements for the development of effective techniques.

CHAPTER 8

Infrared

Since infrared (IR) techniques are being employed in the guidance of missiles today, it is of great importance that the EW officer become familiar with the theory of infrared. Infrared has some distinct advantages over radar under certain tactical conditions, and it is for this reason that it is one of the fastest developing fields today.

It is interesting to note that although military interest in infrared has only recently increased, it was actually being investigated over a hundred years ago.

Sir William Herschel first discovered infrared radiation while attempting to determine the heating powers of various colors. Employing a highly sensitive thermometer as a heat detector, he noted that the temperature increased as the thermometer measured the red or low-frequency part of the spectrum, and reached its peak just below the visible spectrum. He proved that there is an existence of invisible radiant energy which can be reflected and refracted according to the laws of optics.

The theories of Herschel were disputed for several decades, mostly because of the lack of a superior thermometer. A detective device called the thermopile was then developed by M. Million which was used for the next half-century for the detection and measurement of infrared energy. In 1847, N. L. Fizeau and L. Foucault demonstrated that infrared does exhibit interference effects in the same manner as visible light.

Another aspect of infrared under investigation during this period was the maximum wavelength it could have. Fizeau and Foucault first measured infrared in wavelengths up to 1.5 microns. In 1879, the limit was extended up to 2.14 microns by M. Mouton, and in 1880 Curie and Desains extended measurements up to 7 microns.

In 1880, a breakthrough took place in the field when S. P. Langley invented the bolometer, a device which was much more sensitive to temperature changes than previous detectors. This device made it possible for Langley to investigate in detail the atmospheric absorption of solar radiation with a degree of accuracy not possible before and to establish the dispersion laws of various substances.

In 1897, the infrared spectrum was extended to 20 microns by H. Rubens and F. Pashen. Within a few years, wavelengths up to 300 microns were observed. All of these developments helped to bridge the gap between infrared and electromagnetic waves.

During the twentieth century, a great expansion of knowledge has taken place in the entire infrared spectrum. This progress is a direct result of the more precise measurements made possible by the bolometer and improved optical techniques.

The development of precision diffraction gratings and prisms for use in the infrared region of the spectrum has also contributed to this progress. Photoelectric devices as a means of infrared detection have also been developed and, presently, one of the goals of research is to extend the use of these very sensitive detectors to still longer wavelengths where the intensity of radiation from infrared sources becomes quite small.

Perhaps at this point we should compare radar and infrared. A major advantage of infrared over radar lies in the fact that radar is always an active device; that is, it must radiate electromagnetic waves in order to function. Infrared operations may be based, not upon transmission of energy, but on the fact that all warm bodies radiate infrared.

Because it cannot function without transmitting detectable energy, radar always presents a security problem. Also, the difficulty of detecting and tracking targets by radar has been increasing because of the elimination of the aircraft propeller and the trend toward a modern streamlined aircraft shape, which results in a smaller radar-reflecting frontal area. This situation, coupled with higher aircraft speeds, indirectly reduces effective radar range.

On the other hand, higher speeds and more powerful engines provide better heat sources and better infrared targets. Also, jets and rockets spew out gases at extremely high temperatures. This makes detection and tracking easier for infrared equipment, since it depends primarily on total radiation rather than target size.

FUNDAMENTALS OF INFRARED

As shown in figure 8–1, infrared is located in the electromagnetic spectrum between the microwave and visible regions. The wavelength of infrared ranges from 0.75 to 1000 microns. (A micron is one thousandth of a milliameter.)

All electromagnetic waves, including infrared, travel at a speed of approximately 186,000 miles per second. The atmosphere is fairly transparent to all electromagnetic waves except the extreme ultraviolet. In contrast, fog is opaque to all electromagnetic waves except radio and radar waves and, at times, the far-infrared radiations.

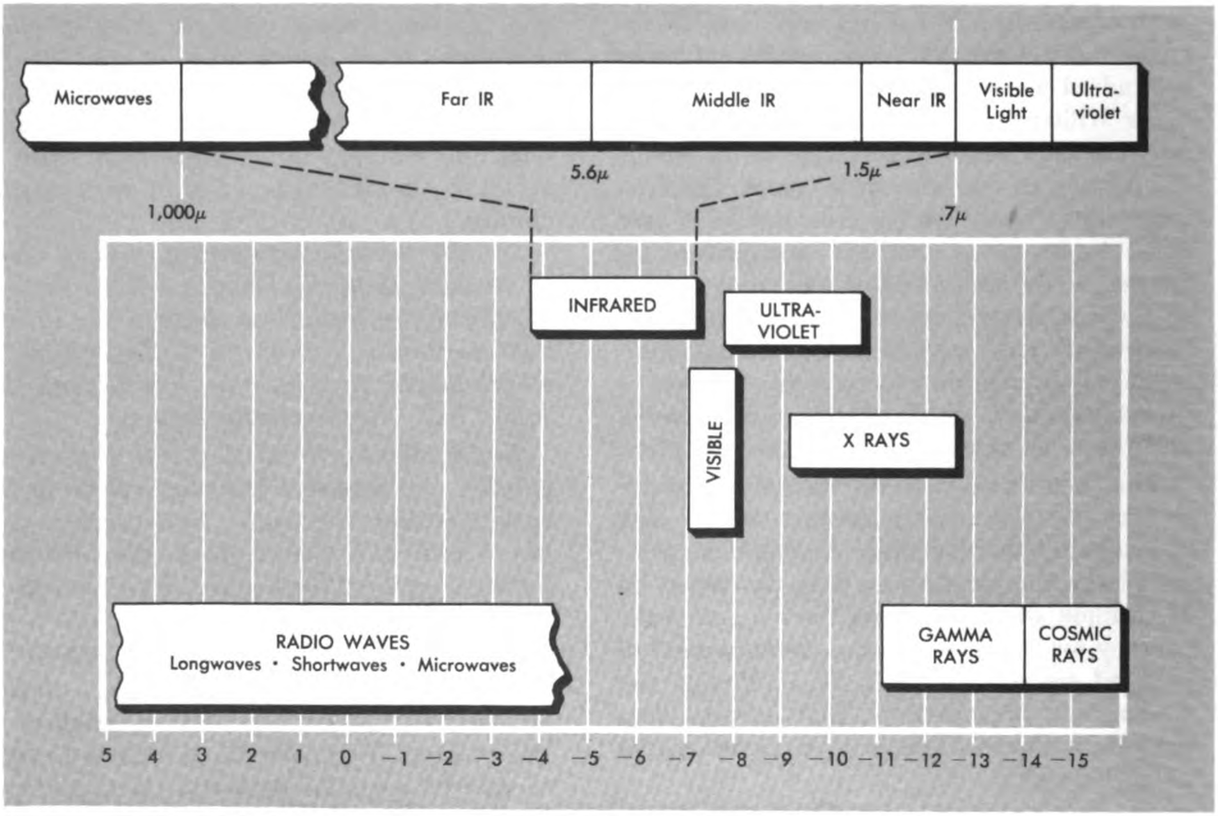

Figure 8–1. *IR Relation to Electromagnetic Spectrum*

The surface of the sun radiates a continuous wavelength from the infrared region to the ultraviolet region. As this radiation passes through the cooler gas layer of the solar atmosphere, certain wavelengths are absorbed.

Because the absorbing medium is in a gaseous state, its atoms and molecules do not absorb all wavelengths equally. They absorb principally the same wavelengths they would emit if heated to a high temperature. Thus, the atoms of one chemical substance will absorb certain wavelengths, while the atoms of another substance will absorb other wavelengths.

Before the radiations from the sun reach the earth's surface, they must also pass through the absorbing gases which comprise the earth's atmosphere. Here again the molecules of the atmosphere absorb principally those wavelengths they would emit if heated to a high temperature.

Each atom and molecule, then, absorbs and emits radiations of a definite wavelength; the exact wavelength depends upon the physical structure of the atom or molecule.

At temperatures above absolute zero, all substances contain molecules which are in motion. Molecular motion produces heat which, in turn, produces infrared energy.

Each curve in figure 8–2 represents the amounts of energy given out over the entire spectrum by a solid at different temperatures. These curves show that at low temperatures very little energy is emitted in the visible spectrum, and that the peak intensity occurs in the infrared region.

At 1000° K, only the visible red is seen, and even that is very faint. At 2000° K the brightness of the red not only increases, but the other colors, orange, yellow and green, appear.

At 3000° K (the temperature of the low-current carbon arc or tungsten filament light), all the visible spectrum is emitted, but maximum radiation is still in the infrared. At 6000° K (the surface temperature of the sun),

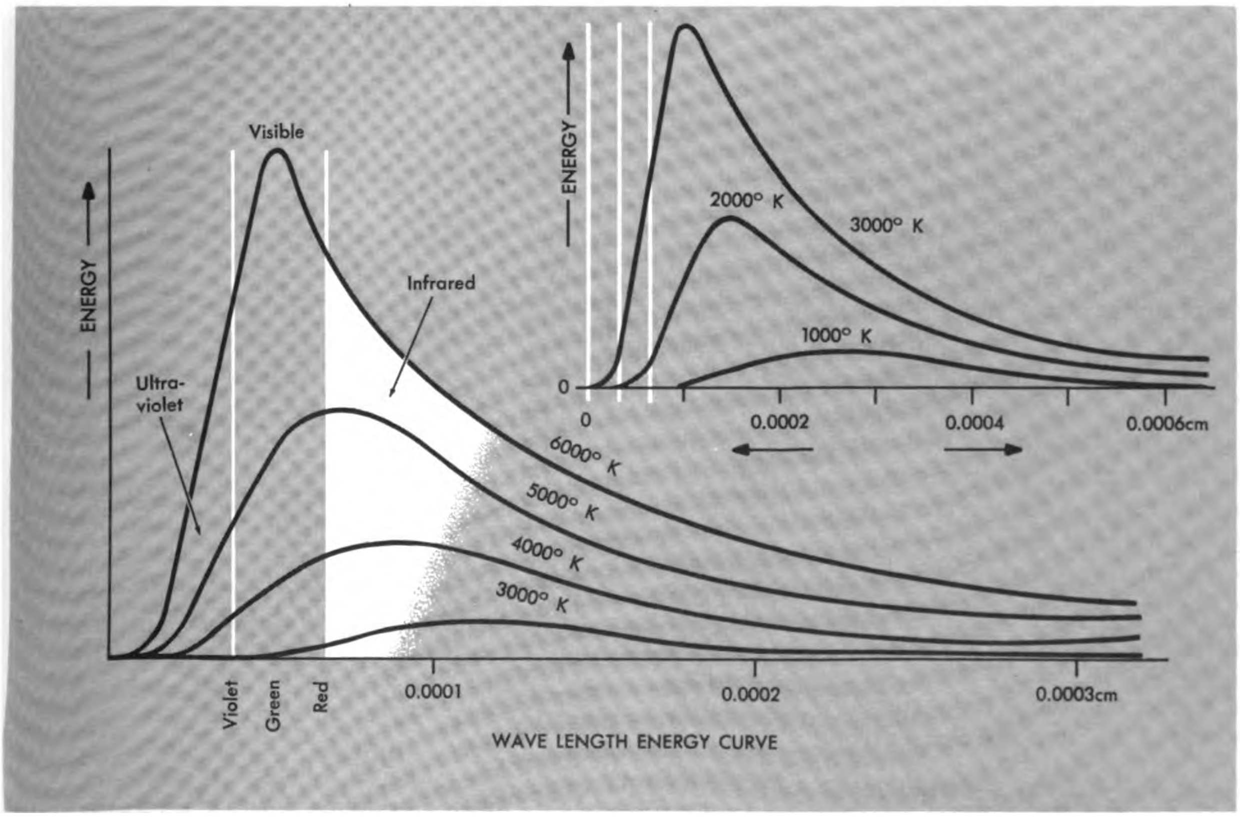

Figure 8–2. *Energy Curves of a Hot Body*

the maximum energy is radiated in the green of the visible spectrum, with an appreciable amount of ultraviolet light on one side and infrared on the other.

Thus, the visible spectrum is but a small band out of all the waves emitted by a body as hot as the sun.

It is an interesting fact that the maximum energy radiated by a hot body shifts to shorter and shorter wavelengths as the temperature rises. To be more exact, if the temperature of a body is doubled, the peak radiated energy shifts to one-half of the previous wavelength. If the temperature is tripled, the peak energy maximum shifts to one-third the previous wavelength, etc.

The total energy radiated by a hot body is proportional to the fourth power of the absolute temperature. This law is known as the Stefen-Boltzmann law.

The Stefen-Boltzmann law only applies to a black body or a body which absorbs all the energy falling upon it. A body like this, which is a perfect absorber, will also be a perfect emitter.

In the laboratory, the closest approach to a black body is a hole in a blackened box. Practically all radiated energy entering the hole is absorbed by the interior of the box. Therefore, the rate at which a body radiates or absorbs energy is not only a function of the absolute temperature, but also of the nature of the exposed surface of the body.

This is known as Kirchhoff's law of radiation. For example, black velvet cloth or a surface blackened by an application of lampblack absorbs about 97 percent of the radiant energy falling on it, and may be considered as a black body. In contrast, polished metal surfaces absorb only about 6 percent of the incident energy. Most other surfaces have absorption ratios between these two extremes.

It can be seen that a black body emits its maximum amount of energy at a wavelength that is inversely proportional to its absolute temperature. In addition, the total amount of energy emitted is proportional to the fourth power of the absolute temperature.

Temperatures of Radiators

A distinction must be made between true temperature and the black-body temperature. The true temperature is defined as the temperature of the body as measured on the Kelvin thermodynamic scale. The black-body (or brightness) temperature is the temperature of a black body whose brightness is the same as that of the body in question for some fairly narrow spectral region. Since the radiation from an actual body can never exceed that from an ideal black body at any part of the spectrum, the black-body temperature of such a body is always lower than its true temperature.

A thermal radiator, such as a heated metal sphere, always appears to be almost uniformly bright over its entire surface. Therefore, the brightness of a spherical surface is independent of the angle at which it is observed. Any surface of this nature is called a diffuse radiator. Diffuse radiators may also be found in the form of a flat surface.

A small element of a flat radiating surface is illustrated in figure 8–3. Such a surface will not appear as bright at point A as at point B. Since the apparent surface area of the radiator at point A is smaller than at point B, the radiation intensity must vary in proportion with the projected area if the surface brightness is uniform.

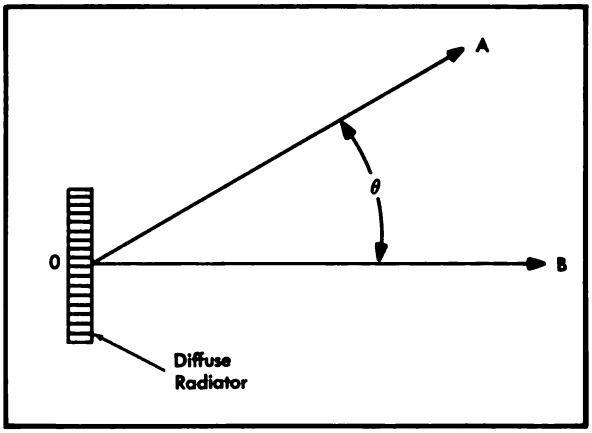

Figure 8–3. *Lambert's Cosine Law for a Radiating Surface*

Emissivity

The infrared energy that an object emits is theoretically a function of its absolute temperature. However, the amount actually radiated depends also on its surface finish. The smoother and more polished the surface, the smaller the percentage of infrared energy radiated at any temperature.

Emissivity is a term used to express the radiating efficiency of any given body and is the ratio of its radiating energy to that which it would radiate if it were an ideal black body. The emissivity ratio is always less than unity, and the Stefan-Boltzmann law must be modified to take this fact into account.

Factors Affecting Radiation Intensity on Distant Targets

The Stefan-Boltzmann law will give the infrared radiation level at a specific target but it will not, for example, give the radiation level which reaches an infrared system located some distance away. As with all forms of electromagnetic radiation, infrared radiation intensity will vary inversely as the square of the distance between the source and the detector.

In addition to the limitations of emissivity and distance effects, infrared energy is also attenuated and scattered quite sharply over some portions of the spectrum and less heavily or not at all in other portions. The atmosphere, therefore, acts quite like a filter, absorbing infrared at some wavelengths, but readily passing energy at other wavelengths without serious attenuation.

The parts of the infrared spectrum which are relatively unaffected by the atmosphere are called windows. Windows are regions of high IR transmissions and low attenuation.

INFRARED OPTICAL SYSTEM

An infrared system contains three principal subsystems: the optical, the detection, and the electronic.

Any discussion of infrared optical components and materials necessarily involves the consideration of the principles of physical optics. Infrared radiation which reaches the surface of a material may be reflected, refracted, or absorbed. In addition, the material may diffract, disperse, or polarize the transmitted radiation. These phenomena are briefly described in the following paragraphs.

Reflection

Radiation reflected by a surface may be reflected "specularly" or it may be scattered. A smooth surface, such as a mirror, is considered to reflect specularly, while a rough surface scatters the radiation which it reflects. The radiation thus scattered is said to be diffused. If the surface reflects specularly, the angle of incidence equals the angle of reflection. No surface ever reflects all the radiation which reaches it.

If the reflecting ability of a material is independent of the wavelength, it is said to reflect nonselectively, and the material, under visible radiation, is white, gray, or black. If the material's reflecting ability depends on the wavelength, it is said to reflect selectively, and the material has a definite color.

Absorption

Radiation which is not reflected by a material is either transmitted through the material or absorbed. Like reflection, the degree of absorption is usually dependent upon the wavelength of the incident radiation.

Transmission

The transmission of a material is the ratio of the amount of radiation transmitted through it to the amount of radiation incident upon it. Transmission is usually expressed in percent. The transmission of a material is a function of the thickness of the material and the wavelength of the incident radiation.

Refraction

The velocity of radiation in one type of material may differ from its velocity in another type of material. Consequently, whenever radiation passes obliquely from one to the other, its direction will be changed. This change in direction is called refraction.

The refraction index is a characteristic of the material in which the refraction occurs. Refraction index depends upon the wavelength of the radiation, and is always stated with respect to the refraction index of air.

Dispersion

The dispersion of a material is defined here as the change of its index of refraction with respect to the change in the wavelength of the incident radiation.

There are five optical properties which must be considered in selecting materials for infrared optical components:

1. Index of refraction.
2. Absorption coefficient.
3. Reflectivity.
4. Transmission.
5. Dispersion.

Materials which can be employed in infrared optical use are sodium chloride, silver chloride, potassium bromide, KRS–5, KRS–6, calcium fluoride, quartz, potassium iodide, and sodium fluoride. In addition, there are many other materials which can be used for this purpose.

Optical System Components

The optical components used in infrared systems are basically the same as those used in visible systems. They consist of lenses, prisms, windows, mirrors, diffraction gratings, and filters. The purpose of these components is to gather or concentrate infrared energy, focusing it as an image in a manner similar to a camera.

DETECTORS

Since the detector is the fundamental infrared sensing device, it may be thought of as the heart of the system. The function of the detector in the infrared system is to respond to ambient and incident infrared radiation collected by its associated optical system. The output then can be used by other communications-electronics devices, or it can be observed by operating personnel.

Most detectors function as transducers; that is, they convert radiant energy into electrical signals. They do this either directly or indirectly as a result of the inherent properties of the material of which they are made.

Classification of Detectors

The principle employed in a detection device determines the class to which it belongs. The two most common classes are thermal and photo detectors.

Some authorities classify detectors according to wavelength sensitivity. In general, thermal detectors are not wavelength sensitive, but respond to radiation throughout the infrared spectrum; the response of photo detectors does vary with frequency (or wavelength) of the incident radiation.

Terminology

Before detectors are described in detail, a few terms employed will be defined.

Sensitivity. Sensitivity, in general, means susceptibility to external action as measured by the speed, range, and degree of response to the action.

Response. Response is defined as the quantitative expression of the output as a function of input under given conditions.

Special sensitivity. Special sensitivity refers to the operating range of a detector, and is measured in terms of the portion of the band of the infrared spectrum to which the detector has a useful response.

Minimum detectable power. The limit of usefulness of a detector is measured in terms of the minimum amount of radiant power (in watts) to which the detector will respond. The minimum detectable power is the point at which a detector output voltage resulting from IR radiation is slightly greater than the internal noise voltage of the detector circuit.

Time constant. The time constant of a detector refers to the time required for the detector to respond to a radiation signal.

Detector Limitations

The function of the detector is critical in infrared equipments and systems. The ideal detector, in general, should possess all of the following properties: broad spectrum response, short response time, low minimum detectable power, high output-to-input ratio, and the capacity to discriminate between targets and their backgrounds.

One of the principal limitations to detector sensitivity and overall performance is noise. The major portion of the noise arises within the detector itself; however, some is attributed to the nature of the radiation and to the atmosphere. The noise which arises within the detector itself is generally of two types, Johnson noise and current noise.

Johnson noise is the predominate noise component in thermal detectors. It is a kind of thermal shot effect caused by internal temperature fluctuations in the sensitive element. The effects of Johnson noise can be reduced by lowering the operating temperature of the detector, and by using as high a chopping frequency as possible.

In photoconductive detectors, especially those made of semiconducting materials, current noise is the most prevalent. It is the result of fluctuations in internal resistance, which, in turn, are caused by random contacts between the semiconductor microcrystals and thermally generated current carriers. Again, cooling is one means of lowering the noise level of the detector output.

Thermal Detectors

Any temperature-sensitive quantity or effect may be employed in the detection of infrared radiation. A change in temperature caused by incident radiation can be made to produce the following secondary effects in the detecting device: the generation of an electromotive force; a change in electrical resistance; or a change in the volume or pressure of a gas.

These effects are utilized, respectively, in the thermocouple, the bolometer, and the pneumatic detector (Golay cell).

The primary advantage of a thermal detector, for military purposes, is its wide spectral response.

Among the several thermal detector types, there are many factors which govern the choice of a particular type for a particular application. Chief among these factors is the chopping frequency that is to be used with the detecting system; there is a definite correlation between the response of the detector and the frequency at which the incident radiation is interrupted.

THE THERMOCOUPLE. The thermocouple is a type of thermal device whose basic principle is the Seebeck effect. This effect is present in a circuit using two dissimilar metal conductors; when the two junctions are at different temperatures, an electromotive force is generated and current flows in the circuit. When a thermocouple is used as an infrared detector, the incident radiation produces the needed temperature difference at the junction.

A simple type of thermocouple is shown in figure 8–4. It consists of two dissimilar metals (A and B) joined at two junctions, with a radiation receiver at one junction and the other ends connected to an electrical measuring device. The radiation falling on the receiver heats one junction of the two metals. The other junction and the remainder of the circuit may be considered as being held at a constant temperature.

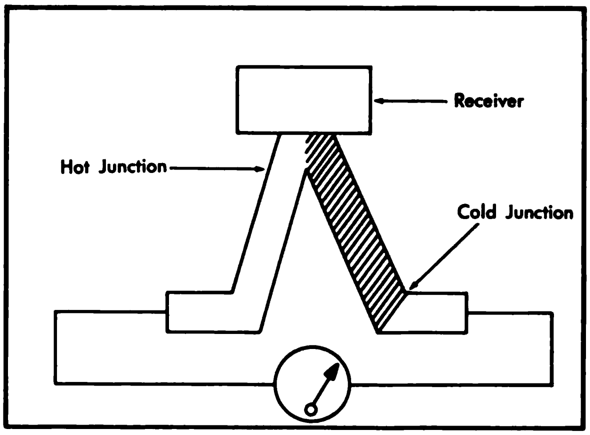

Figure 8–4. *A Thermocouple Detector*

There are several factors governing the choice and arrangement of materials in thermocouple circuitry. Among these are:

- Thermal capacity. This is a measurement of the amount of heat energy a substance must absorb to raise its temperature one degree. For the detector itself, low thermal capacities are desired for maximum sensitivity.
- Thermal conductivity. This is a measure of the transfer of heat in a given material. Normally, low thermal conductivity is desirable, so that changes in detector temperature do not affect the other circuit elements.
- Thermoelectric constants. These are the electrical characteristics which vary with temperature changes, including such phenomena as electrical resistivity and conductivity.

THE BOLOMETER. The thermoelectric effect which is exploited in the bolometer involves a change in electrical conductivity of the detector material when it is subjected to changes in temperature. The bolometer is used in a circuit with a small current passing through it constantly, so that changes in its conductivity produce variations in the current flow.

The operating characteristics of the bolometer are:

- Stability. Stable operation of a bolometer circuit depends largely upon the supply voltage, the sensitive element, and the value of load resistance. If these are properly chosen, the temperature rise caused by the steady circuit current will be within the normal operating range of the bolometer.
- Time constant. Time constants for bolometers are generally faster than for thermocouples, permitting the use of higher chopping frequencies.

Bolometer detectors are of three different types: the metal strip, the thermistor, and the superconductor.

Figure 8–5 shows Langley's (metal strip) bolometer. It consists of a Wheatstone bridge circuit in which two strips of platinum are used in two of the arms. For the other two arms, resistors equal in value to the platinum are used (one is variable for balancing the bridge).

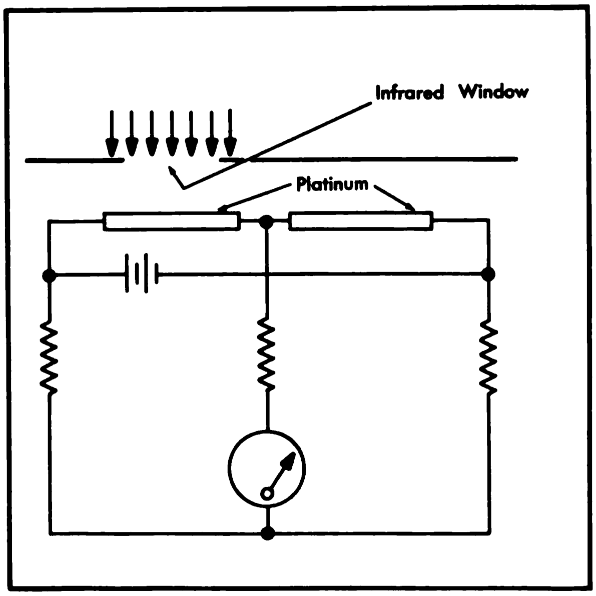

Figure 8–5. *The Langley Bolometer*

The platinum strips are blackened and mounted near each other so that they are equally affected by changes in ambient temperature. Only one of the strips is exposed to incident radiation, so that any change in its resistive value will unbalance the circuit. The out-of-balance current is measured with a galvanometer, yielding a useful indication of radiation intensity or wavelength.

The term thermistor bolometer refers to a bolometer which employs semiconducting materials. It has several advantages as a thermal bolometer. Among these are very good sensitivity, a minimum detectable power which is about twice as good as that of the best thermocouples, and a good time constant.

The superconducting bolometer takes advantage of the unusually high conductivity which exists in certain materials at very low temperatures. When a bolometer circuit is cooled and operated as a superconductor, it exhibits a very short time constant, good sensitivity, and very low minimum detectable power. A major disadvantage of this type of bolometer is the required cooling apparatus.

Photo Detectors

Photo detectors differ from thermal detectors in that they are wavelength sensitive. They are also known as quanta detectors since they will only respond to certain minimum quanta or energy of sufficient level and frequency to "trigger" them.

Photo detectors have shorter time constants than thermal detectors. Photo detectors also have a more accurate response to rapid changes in infrared radiation levels.

The most significant class of photo detectors is made up of those devices which employ photoelectric effects. These include photoemissive, photoconductive, and photovoltaic detectors. Detectors which depend upon luminescent properties may also be considered photoelectric devices. The other important class of photo detectors is the photographic.

PHOTOEMISSIVE DETECTORS. Photoemissive detectors respond to a photoelectric effect in which electrons are emitted from the surface of a substance when exposed to infrared radiation. The emitted electrons are directed (or attracted) to an anode or plate, and the current is proportional to the intensity of incident radiation when applied to an output circuit as in figure 8–6. This operating principle is also used in the electron image tube.

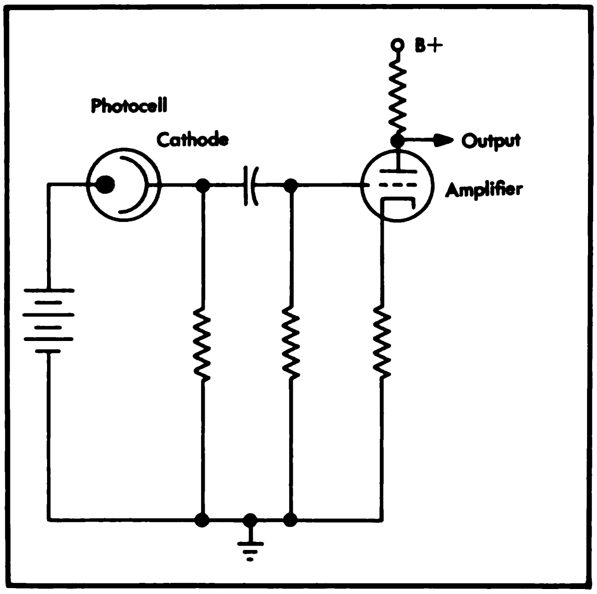

Figure 8–6. *Photoemissive Detector*

The vacuum cell is the simplest form of photoemissive detector. It contains only a cathode and an anode in an evacuated envelope.

PHOTOCONDUCTOR DETECTORS. The photoelectric effect, by which photoconductive detectors operate, depends upon the fact that some materials exhibit a marked increase in electrical conductivity as a result of infrared illumination.

Photoconductive detectors differ significantly from thermal detectors in several basic characteristics. Photoconductors have a definite long-wave limit to their sensitivity or overall response, since they are wavelength-sensitive, quanta-detecting devices.

The principal material used in photoconductive detectors is a semiconductor. Semiconductors are most suitable for this application because of their ability to reflect or absorb high-energy light rays while transmitting the low-energy infrared rays.

Semiconductors possess two kinds of charge carriers: negative electrons and positive holes. The charge carrier concentration increases with temperature or upon exposure to infrared radiation.

This is the primary photoconductive effect. The electrons which move into the conductive band can circulate more freely, thereby generating a current (or an increase in current, in a practical detector circuit). Eventually, of course, these electrons will return to their original energy level unless they lodge in an electron trap. Under steady infrared illumination, a current equilibrium will be attained. The primary photoconductive effect is proportional to the intensity of infrared illumination.

The operating characteristics of the photoconductive detectors are:

- Sensitivity. The sensitivity of photoconductors is stated as being 10 to 100 times greater than the sensitivity of thermal detectors.
- Spectral sensitivity. At normal operating temperatures, spectral sensitivity of photoconductors extends to about 9 microns.
- Time constant. While not generally as fast as most photoemissive detectors, photoconductor detectors are considerably faster than thermal detectors, with time constants measured in microseconds rather than milliseconds.

PHOTOVOLTAIC DETECTORS. The operation of the photovoltaic detector is similar to that of the thermocouple, since the output voltage is obtained by IR radiation of a junction of dissimilar metals. Their difference lies in the fact that the property of the materials which are utilized is photoelectric rather than thermoelectric.

There are three types of photovoltaic cells: the mosaic, the thallium sulfide, and the lead cell.

LUMINESCENT DETECTORS. The fact that some substances become luminescent when stimulated or excited by radiation is the operating principle of luminescent infrared detectors. Luminescence is the emission of light not caused directly by incandescence; thus it occurs at low temperatures.

There are many detector applications which require a pictorial representation of the observed radiation source. These applications are usually found in conjunction with some function requiring direct observation and consequent action by a human operator. Most of these image-formers are photo detectors which work on the photoconductive or photoemissive principle.

FILTERS

For infrared applications, a filter is used to isolate a particular part of the spectrum. Filters can be classified by their spectral characteristics. A band-pass filter is one which transmits radiation over a band of wavelengths. One of the most important requirements of a filter is a sharp cutoff on each side of its band-pass characteristic.

Filtering action occurs because of one or more of the following phenomenon: selective absorption; selective refraction; selective reflection; scattering; interference; or polarization.

Selective Absorption Filters

All forms of matter absorb radiation selectively. Unfortunately, most substances do not have absorption bands in the infrared region and those that do have rather broad bands.

A selective absorbing substance can be used as a low- or high-pass filter by merely passing radiation through it. The substance can also be incorporated in a "chopper" (a rotating shutter located in front of the detecting component) to form a band-pass filter system in conjunction with the detector.

Among the absorption materials are:

SOLIDS. There are many solids which have absorption edges (cutoffs) in the infrared region. These range from glass, at approximately 2.5 microns, to KRS–5, at approximately 40 microns. In general, cutoffs of solids are not sharp and they are not ideal as filters.

DYES. Dye materials have been developed primarily as high-pass filters to cut off any visible light from a given source. Such filters have been made of plastics containing dyes, of glass coated with plastic dye solution, of dyed cellophane, nylon, or polyvinyl, and alcohol films.

SEMICONDUCTORS. Semiconductors can be used as high-pass filters. Silicon and germanium are particularly useful for removing visible and near infrared radiation.

MISCELLANEOUS. Black paper can be used to cut off the region below 100 microns, while camphor soot on celluloid has a pass band from 30 to 130 microns.

Selective Refraction Filters

The fact that the refractive index of optical materials varies with wavelength makes possible the construction of highly selective filters. If a beam of infrared energy is passed through an optical system, such as a lens or prism, it will be bent according to the laws of refraction.

Selective Reflection Filters

Many crystalline materials reflect selectively. These materials may have a reflection coefficient as high as 90 percent for a narrow wavelength or several bands, compared with 5 percent for all other wavelengths reflected. For example, quartz reflects about 75 percent at about 9 microns, and about 3 percent at less than 8 microns.

Quartz can also be used to filter out wavelengths above and below its maximum reflection wavelength band. It performs most efficiently if the radiation from the source is reflected several times by two or more quartz mirrors.

Scattering Filters

Small particles of one material distributed throughout another material serve as a medium that may have transmission characteristics very different from those typical of its bulk form. When the material is in such a distributed particle form, its transmission characteristics depend on particle size, layer thickness, refractive index of the material, and refractive index of the medium.

Interference Filters

Interference phenomena between two parallel plates can be utilized to make both reflection and transmission-type infrared filters.

REFLECTION-TYPE INTERFERENCE FILTERS. In its simplest form, a reflection-type interference filter consists of a dielectric and a semireflective metal. The reflectivity of such a filter depends on the thickness of the dielectric layer and its refractive index at that particular wavelength.

TRANSMISSION-TYPE INTERFERENCE FILTERS. The simplest form of transmission-type interference filter consists of a thin film of dielectric material coated on both surfaces with a semireflecting metal layer. Maximum transmission occurs when the thickness of the dielectric layers are integral multiples of ½ wavelength of the radiated energy.

These simple forms of transmission-type filters are of little value in military applications because of their low transmission percentage and their wide band-pass characteristics.

Polarization Filters

As yet, polarization filters have not been used extensively in infrared applications. Such filters have three main components; these include two polarizers and a birefringent element.

IR DOMES

An infrared dome (IR dome, comparable to a radome) is required to protect infrared equipment mounted externally on an aircraft or missile. Ideally, it will not affect the aerodynamics of the airframe, and it will be transparent to the infrared radiation used by the equipment.

Like the infrared window, the IR dome must have good optical characteristics, the strength to withstand severe temperature changes and other stresses and strains, and a resistance to wind abrasion.

If the shape of an infrared dome could be selected primarily on the basis of its aerodynamic characteristics, it might be a cone, an ellipse, or a parabola. But, because of its optical requirements, the dome usually takes the shape of a hemisphere.

A hemisphere has considerable drag, particularly when installed on a jet aircraft or missile, so a spike may be added to it to reduce the drag as much as possible.

The dome may be mounted in the nose, in the wing, or in a pod under the belly of the aircraft. In any of these locations it is subjected to heating due to friction with the air.

Two things may happen when it becomes hot: the detector may "detect" the dome instead of objects beyond it; or the dome may melt. Consequently, infrared dome material should have a high melting point and a high conductivity for heat. However, the material to be used for a dome is chosen largely because it has a high transmission in the spectral region to which the infrared detector is sensitive.

TARGET DISCRIMINATION

Targets are generally divided into two types:

- Active targets, which generate their own infrared energy.
- Passive targets, which reflect or reradiate infrared energy that reaches them from the sun.

Piston-engine aircraft are as detectable by radiation from the side as from the tail. Jet aircraft are far more easily detected by radiation from the tail. As the speeds of aircraft increase, their noses tend to become hotter. Aerodynamic heating of the leading edges of the metal skin can contribute significantly to the radiation temperature.

The total amount of infrared energy radiated by a black-body type of target is proportional to the fourth power of its absolute temperature (T^4) according to the Stefan-Boltzmann law. So, the hotter the target, the longer the range at which it can be detected.

A jet- or rocket-powered aircraft is a better target than a piston-engine aircraft for two reasons: its engine temperature is higher and its skin temperature is higher because it is flying faster.

Backgrounds

The backgrounds from which a target is to be distinguished can be divided into two types, day backgrounds and night backgrounds.

On a clear day, the background radiation from ground-level objects consists of long wavelengths which are radiated according to their temperatures and emissivities, and shorter wavelengths, or reflected sunlight. The long-wavelength radiation is a result of heating by the sun.

The temperature to which a body is heated by the sun depends partly upon the intensity of the sunlight, the thermal properties of the object, and the reflectivity of the object.

Night backgrounds are due to the night sky airglow, the aurora, starlight, etc. The infrared emission of the sky at night may be at least as strong as that in the daytime; but, when it is compared to scattered and reflected radiation from the sun and the emission from the atmosphere, the night sky airglow is negligible.

This means that the sky background at night consists essentially of emission from the atmosphere, and therefore must be considered at lower altitudes. At higher altitudes, when the observer is above the effective water vapor atmosphere, the average level of the night sky background will be due to the night sky airglow.

Distinguishing Between a Target and its Background

The operational value of an infrared system for reconnaissance or weapon control depends upon the ability of the system to distinguish targets from backgrounds.

Since a detecting device is automatic, it must have sufficient intelligence to distinguish between true targets and backgrounds. Examples of background clutter are clouds, mountains, buildings, the earth's surface, etc. To enable the detecting device to discriminate, the designers consider the characteristics which differentiate the target from the background. The target is usually smaller or hotter than the background.

TARGET SMALLER THAN THE BACKGROUND. If the target is smaller than the background, the detecting device can be made to prefer small targets by incorporating a space filter reticle. In addition, the detecting device may be designed to have a narrow field of view.

Decreasing the field of view increases the ability of the system to distinguish between target and background. It also increases the sensitivity and range of the detecting device.

TARGET HOTTER THAN THE BACKGROUND. If the target is hotter than the background, the spectral characteristics of the radiation emitted by the target will differ from those emitted by the background. Consequently, the contrast between the target and the background can be increased by using optically selective filters that have limited spectral ranges of transmission.

Narrow band filters which block infrared wavelengths for which the atmosphere is transparent may be used in conjunction with the detectors of limited spectral sensitivity. These filters pass radiation in the high target-to-background contrast regions, and block radiation for which the atmosphere is transparent. Thus, they improve the contrast between target and background.

The effect of background brightness can be reduced by removing the visible radiation from the background. This is accomplished by two features of an infrared system: filters, which eliminate the visible radiation (below 1 micron); and detectors, which respond only to infrared radiation.

Transmission Through the Atmosphere

The atmosphere is the medium through which the infrared radiation passes between target and detector. As such, it may be discussed in terms of its absorption, scattering (diffuse reflection), and transmission properties. The atmosphere is considered to transmit what it does not absorb or reflect.

If there were no atmosphere, the infrared energy reaching the detector would vary inversely with the square of the distance between the target and the detector. If the atmosphere did not contain moisture, infrared targets could be detected through it at phenomenally long ranges. Transmission of infrared radiation, in fact, would be considerably better than transmission of visible radiation. However, for both infrared and visible radiation, large transmission losses occur because of scattering and absorption by water vapor.

SCATTERING. Because infrared radiation occurs at longer wavelengths than visible radiation, it is less likely to be scattered by small particles in the atmosphere.

When water condenses into minute droplets, or when other particles such as dust or smoke are suspended in the air, the result is haze. Haze or cirrus clouds, which contain small water particles, scatter infrared radiation much less than visible radiation.

Figure 8–7 shows the effect of haze on the transmission of infrared radiation over a 6,000-foot range.

Clouds or heavy fog containing water particles of diameters larger than the near infra-

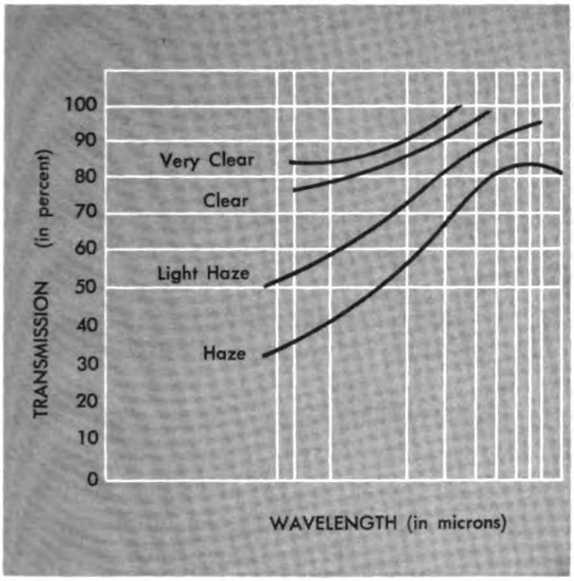

Figure 8–7. *Atmospheric Transmission for Four Degrees of Haze*

red wavelengths scatter infrared radiation almost as much as visible radiation.

Absorption. In the near infrared region, the atmosphere may absorb most of the radiation. The amount of absorption is directly proportional to the amount of water vapor in the air.

The amount of water vapor in the path between an infrared detector and its target varies with time, altitude, temperature, and angle of vision. Detector performance is impaired only slightly by atmospheric attenuation in high-altitude air-to-air combat. But for air-to-ground, ground-to-air, and ground-to-ground IR applications (for example reconnaissance, bombing, or air-to-ground missile attack), the range of detection may be severely limited by atmospheric absorption and scattering.

Figure 8–8 shows the effect of water vapor on the transmission of infrared energy in the atmosphere. The regions of high transmission are referred to as windows.

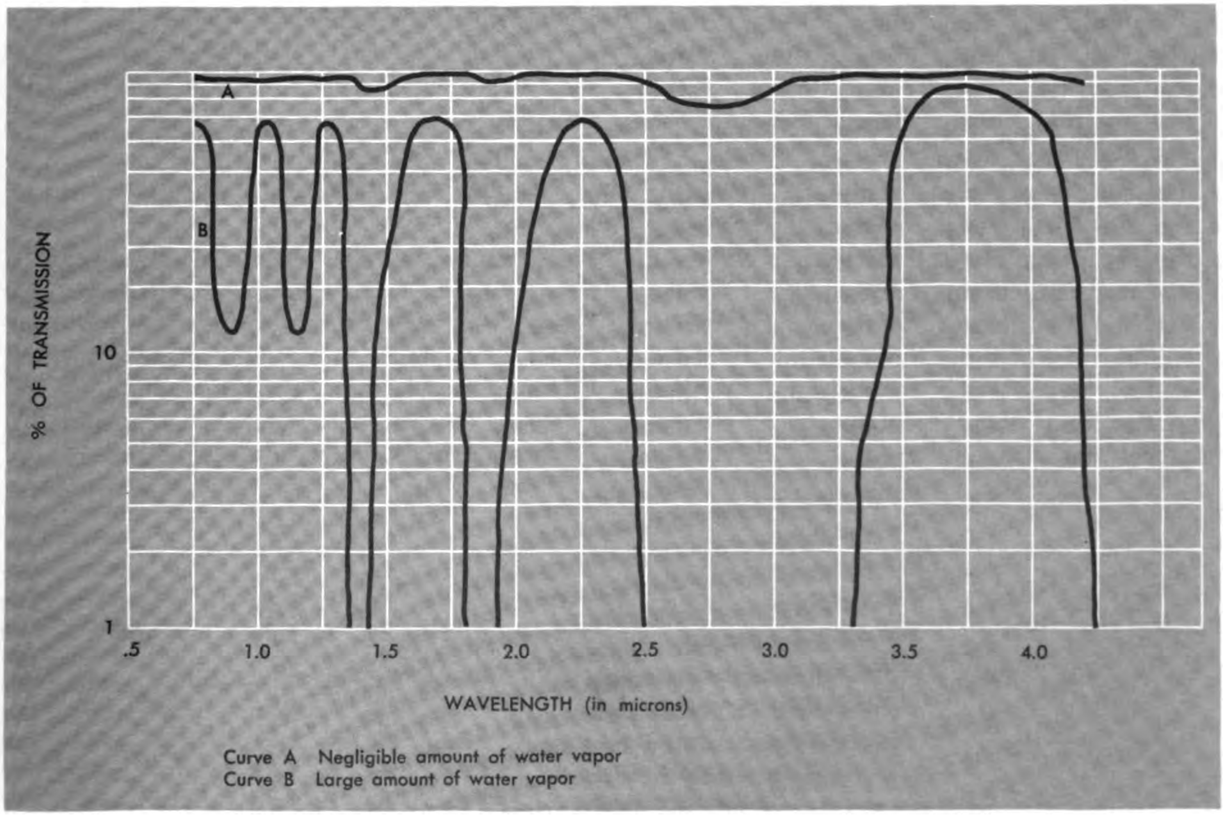

Figure 8–8. *Water Vapor Absorption in the Atmosphere*

COMPONENTS OF INFRARED SYSTEMS

The inception of infrared systems has naturally led to the development of heretofore unusual components. These systems require special receivers, transmitters, display systems, and amplifiers in order to meet military operational requirements.

Infrared operational principles are somewhat removed from the principles employed by radio and radar. Several of the differences are the inclusion of critical optical systems, the development of special modulating systems, and the method of low-frequency, low-noise amplification used in infrared receivers.

Receivers

Reception of infrared radiation is accomplished by receiver units which generally consist of a reflective or refractive optical system, an infrared detector system, an amplifying circuit, and a decoding device.

The blocks in figure 8–9 illustrate a typical infrared receiver. Radiations which are either emitted or reflected by the target are collected by the optical system and focused into the reticle. The reticle itself is a slotted, opaque plate which permits the energy to pass to the field lens, from which it is refocused onto the infrared sensitive detector.

The reticle may be continuously moved at a high speed so that the image of the radiating surface is alternately transmitted and chopped. This causes a flickering infrared signal (coded by the reticle's action) to be transmitted to the detector, which produces a similarly coded electrical signal. The coded signal is then amplified and decoded by electrical or mechanical means.

The output of the decoding device is used for indication or for automatic control of the angular position of the target sightline relative to the position of the infrared receiver.

The detailed design of the reticle is one of the most important features in the performance of the infrared receiver. The reticle is responsible for accomplishing the following operations:

1. It modulates the incident energy at a frequency suitable for operation of the detector.
2. It encodes the signal with information as to the relative position of the target in space.
3. It discriminates against false targets and backgrounds, insuring that the true target is selected by virtue of its size, or "color," or both.

Transmitters

The basic components of most infrared radiation transmitters include a source of energy and a filter that restricts visible light. The source generally emits energy over a wide band which includes the visible portion of the spectrum; visual security is provided by the filter. In some infrared transmitting applications, it is also necessary that a modulator be included.

INFRARED DATA CHART

A composite chart of infrared data may be constructed as shown in figure 8–10 to provide ready reference information on infrared spectrum relation of sources and on detector and optical materials for infrared equipment and systems. Such a chart represents considerable information of an IR nature.

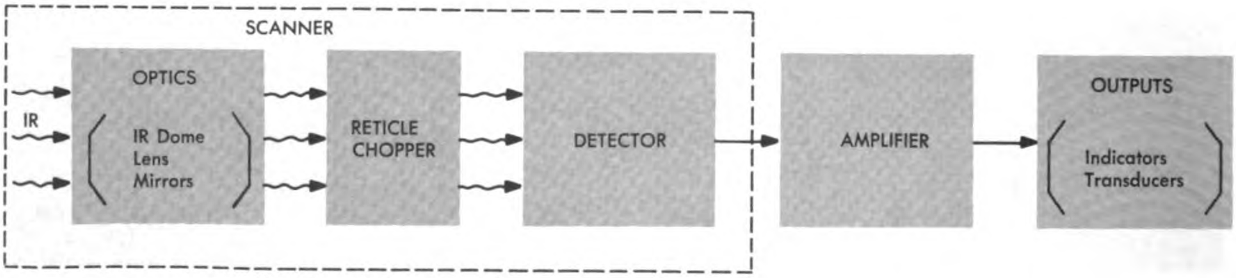

Figure 8–9. *IR Receiver Diagram*

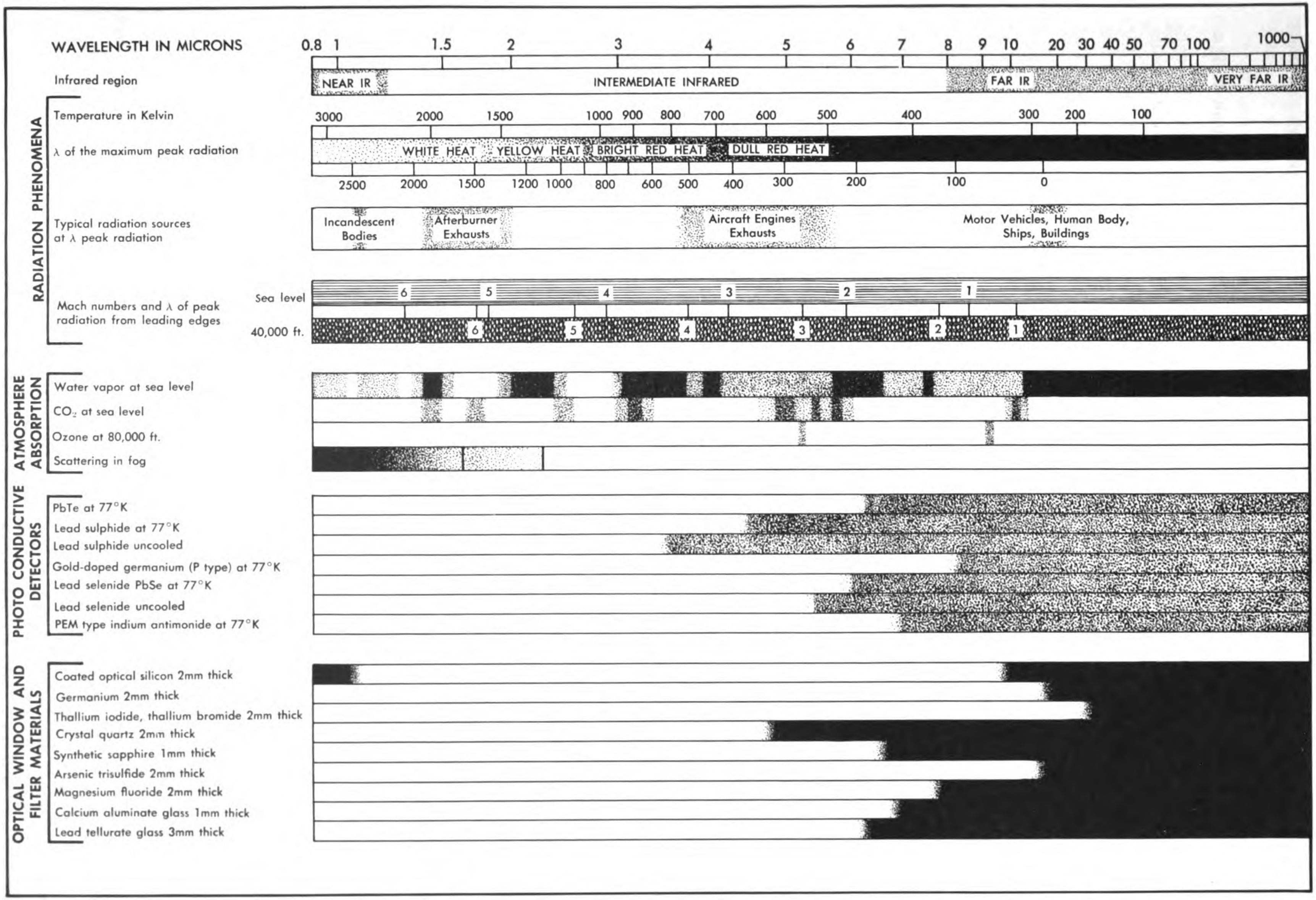

Figure 8–10. *IR Data Chart*

The chart is constructed on a logarithmic scale of the wavelength for the infrared spectrum and is divided into the near, intermediate, far, and very far infrared regions. These regions are arbitrary divisions associated with the development of detectors and optical materials. Another area of interest is the temperature of the source of IR radiation.

The first major block illustrates the relation of temperature to the wavelength at which the peak radiation occurs. The temperature relations shown are for black-body radiations. Targets of interest are shown as grey bodies. Shaded areas on the chart indicate areas where the wavelengths of peak radiation may occur. The peak wavelength of IR energy from the plume of a rocket falls to the left of the scale at 3500° to 4000° K.

The second block of the scale shows the bands of atmospheric attenuation according to wavelength. This scale identifies the windows of little or no attenuation through which energy may be transmitted for considerable distances. It emphasizes the important wavelengths that search, detection, homing, and fire control equipment are able to operate on successfully.

The block on detectors graphically illustrates the available materials for use as detectors and the wavelengths to which they will respond. No attempt is made to compare the sensitivities of the various detectors. The light areas only indicate the wavelength to which the particular material will respond.

The last block shows the wavelength at which the material listed transmits IR energy. These materials may be used for IR optical systems at these wavelengths.

INFRARED COUNTERMEASURES

The development of infrared systems has been paralleled by the search for effective infrared countermeasures.

Possible infrared countermeasures fall into two categories, design and tactics. Design countermeasures affect the inherent radiation patterns of infrared targets. Tactical countermeasures, which include defensive movement of the target and the use of infrared screens or decoys, complicate the already difficult problem of target discrimination.

Decreasing Target Detectability Through Design

The detectability of a target may be considerably decreased by one of several modifications in its design. These include a reduction in the intensity of radiation at its source, shielding of the radiation, or the introduction of counteragents at the radiating source.

REDUCING THE RADIATION LEVEL. The most direct means of reducing the intensity of target radiation is by operation at lower temperatures. This might also be desirable from the standpoint of operating efficiency. However, there are obvious limits to this approach, since certain levels of radiation are inherent in the function of equipment; a reduction may decrease the effectiveness of the equipment, whether it be a jet fighter or an artillery piece.

SHIELDING THE RADIATION. A more feasible approach involves the interposition of a shield between the radiation source and possible detectors. This can be done directly on some ground equipment by placing the exhaust pipe and muffler of a vehicle on the underside, or indirectly by erecting mounds of soil or sandbags around an artillery emplacement.

The effectiveness of shielding a target is related to the type of detecting equipment being used against it. The narrow spectral range of a photo detector makes it very sensitive to small areas of an active target. When used to detect a vehicle, for example, a photo detector sees only the exposed exhaust pipes, mufflers, radiators, and possible exhaust gases. The radiation signals from these parts of a vehicle are highly directional, and the signals rapidly diminish when the engine stops.

It has been conjectured that an increase in the size of the condensation trail of jet aircraft might be effective, since this attenuates the infrared radiation of the tailpipe as much as 50 percent.

Tactical Countermeasures

The most effective types of countermeasures will have to be of the tactical type. In fact, in the case of jet aircraft which use afterburners, these may be the only effective countermeasures. For aircraft in general, such tactical maneuvering may be one of the following three types:

- Maneuvering the plane out of the range or field of the detector.
- Flying the plane between the detector and the sun. This will greatly hinder separation of the plane from its background, and possibly blind the detector.
- Interposing clouds or a fog bank between the plane and the detector by selecting a certain flight path. The water vapor in the detection path will either partly or completely block the infrared radiation from the plane.

All of the above techniques presuppose awareness by the aircraft crew of the presence and direction of imminent attack. This may come in the form of attack by interceptor aircraft and air-to-air infrared-guided missiles.

Since initial engagement by ground-based search and track systems will probably be radar-controlled, and since the fire control system of the interceptor aircraft will also be radar controlled, the initial problem of an evading aircraft involves the use of radar countermeasures. Infrared countermeasures are concerned chiefly with the evasion of air-to-air missiles which utilize infrared homing devices.

Figure 8-11 shows that for a 1.5g turn by the target, the missile will lose guidance approximately 3.8 seconds after it has been launched. For a 2.5g horizontal turn by the target, it will lose guidance about 1.6 seconds after launching. These estimates are made for a missile launched on a line with the center of the tailpipe from a distance of 3.9 miles.

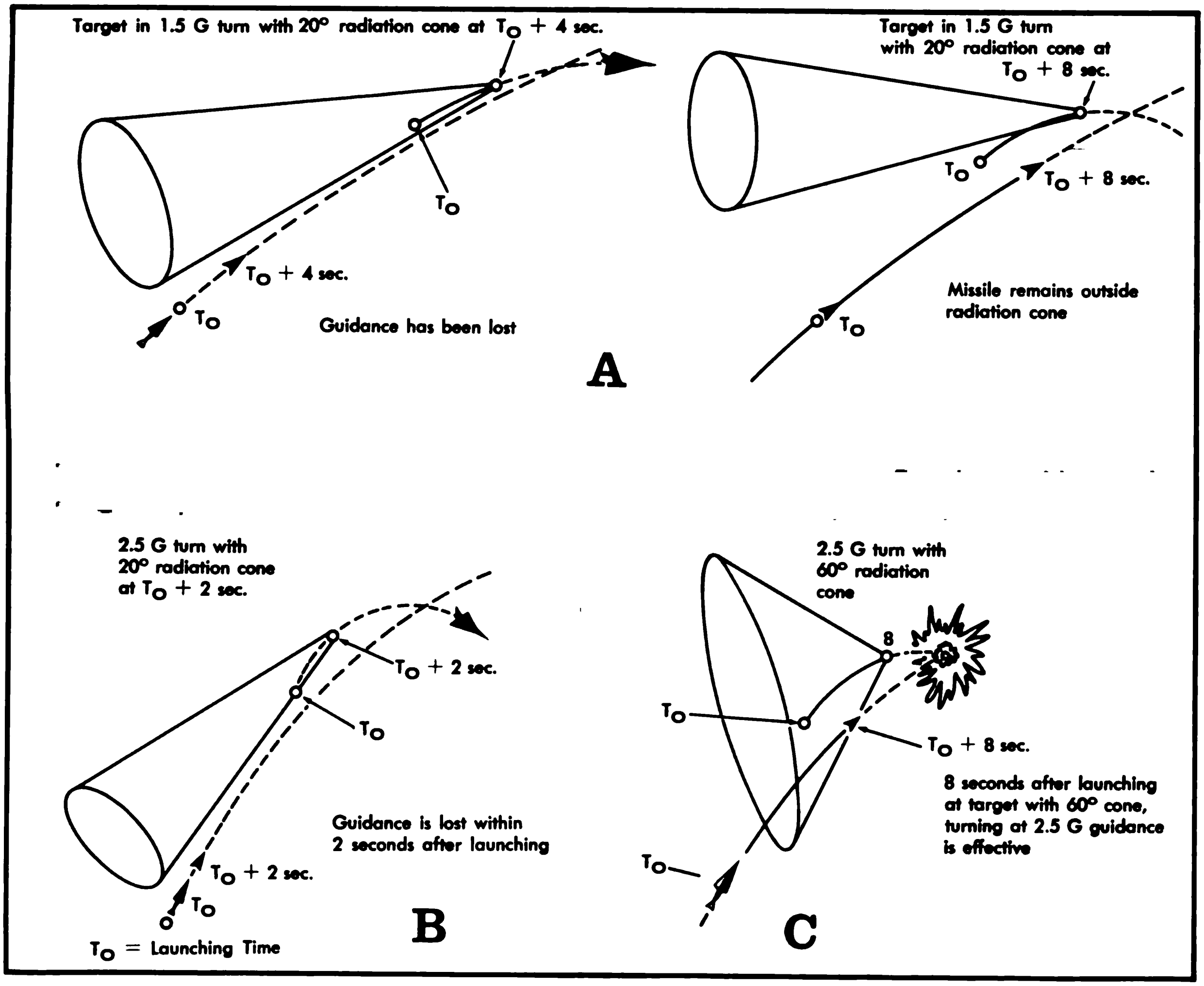
Target in 1.5 G turn with 20° radiation cone at T_O + 4 sec.
T_O
T_O + 4 sec.
T_O
Guidance has been lost
Target in 1.5 G turn with 20° radiation cone at T_O + 8 sec.
T_O
T_O + 8 sec.
Missile remains outside radiation cone
T_O
A
2.5 G turn with 20° radiation cone at T_O + 2 sec.
T_O + 2 sec.
T_O
Guidance is lost within 2 seconds after launching
T_O + 2 sec.
T_O
T_O = Launching Time
B
2.5 G turn with 60° radiation cone
8
T_O
T_O + 8 sec.
8 seconds after launching at target with 60° cone, turning at 2.5 G guidance is effective
T_O
C

Figure 8–11. *Missile Guidance and the Radiation Cone*

On the other hand, a target with a rear radiation cone of 60 degrees could not evade a missile by making a 2.5g turn. Launched astern of the target, the missile would have more than 8 seconds of guidance.

IR Tactical Devices

SMOKE. It may be possible to decrease the infrared detectability of an aircraft by creating smoke in its exhaust.

FLARES AND DECOYS. Some theoretical studies and preliminary tests have indicated that flares may decrease the vulnerability of an aircraft to infrared guided missiles. In a given situation, the flare would serve as a decoy. It would be ejected from the aircraft attempting to evade infrared detection. The probable requirements for such a flare are as follows:

- It should radiate 20,000 watts or more between 0.75 and 3.0 microns, reaching this brilliancy in about 0.25 seconds and continuing for 6 seconds or more.
- It should not produce radiation which can be seen by the naked eye beyond ½ mile.

Such a flare might be contained in a case and fired from a photoflash cartridge ejector. In operational use, several flares would be ejected in a pattern. The pattern should be designed to cause the greatest confusion to an infrared guided missile.

The use of flares should be particularly effective for target aircraft whose tailpipes radiate in a narrow cone. The following factors would have to be considered in devising a flare ejection pattern:

- The missile's dynamic response.
- The precession rate of the missile's detector head.
- The target aircraft's speed and maneuverability.

Another proposed decoy method utilizes so-called "balls-of-fire." The decoy devices consist of hollow spheres of carbon heated to about 3000° K by the ignition of materials contained within them. Like the flares, these balls would be ejected in patterns rather than separately.

It has been suggested that a bomber might tow a decoy target behind it. Such a decoy could be 20 feet long and have a wing span of 16 feet. A towed decoy might be an excellent infrared countermeasure if it were small enough to be carried in the aircraft until attack was expected.

INFRARED COMMUNICATIONS

The simplest source of infrared energy is the common tungsten lamp, which is widely used in code operations by keying the lamp circuit. The principal disadvantage of this device is its inherently slow speed of response which limits Morse code operations to a speed of about eight words per minute.

A high-speed mechanical shutter will increase the speed of signaling, but other complex design problems are still being studied. These problems include resistance to shock, vibration, and weathering, and continuous operation under adverse conditions.

The rigid shock and vibration requirements have led to the development of rugged and shockproof tungsten lamps for use in all types of operations. However, the limitations in code speed remain unchanged, since the lamp filament must still be keyed. A further means of increasing the speed of operations is by reducing the actual mass of the tungsten filament. This method, in conjunction with the use of half-wave rectification, has rendered tungsten-lamp transmitters capable of achieving code speeds and modulation percentages which are within the range of most infrared receivers.

The primary requirement for infrared filters is the restriction of the visible-light radiation from the source. Filter design parameters include characteristics of the source, the human eye, and the intended receiving element.

Modulation of infrared radiation at a transmitting source is basically accomplished by one of two means: either the radiation source itself is modulated, or the outgoing beam of radiation is interrupted at a preset rate.

In the first method, electrical modulation of the current through a tungsten lamp or a gas discharge source is the commonly employed practice. For modulating the outgoing beam, electro-optical devices like the Kerr cell have recently been considered, but most military systems use mechanical modulation. This mechanical modulation is effected through the

use of vibrating mirrors and various beam-chopping devices. In RF systems, modulation is produced by causing supersonic vibration of some optical element.

The major advantage of electrical methods of modulation is their high degree of efficiency. Although mechanical methods are not quite as efficient, the equipment is generally lighter in weight. The modulation technique that is selected for a system may determine such characteristics as size, power, efficiency, and security of the source, and may largely affect the design of the receiving equipment.

Infrared receiver amplifiers are designed with primary consideration to detectors with which they will be employed. This is done to avoid restriction of the inherent sensitivity of the detector due to limitations produced by incompatible amplifier design.

One important condition is that the amplifier have a lower noise level than the detector itself. This noise problem also arises in the selection and design of all auxiliary equipment, such as the power source for the amplifier.

Another feature taken into consideration is amplifier gain. A constant gain is highly desirable, with the signal level remaining virtually unchanged during time of measurement.

Also, with an AC amplifier, the interrupting or chopping frequency should allow the longest practical interval of observation time.

The most widely used forms of amplification for the weak output signals from the infrared detectors are DC and AC amplifie and the photomultiplier.

CLASSIFICATION OF SYSTEMS

Infrared systems are generally divided i two major classifications according to th basic operating characteristics. One of th groups is composed of passive systems wh do not employ any transmission of infrared radiation. These systems operate by detecting the radiation which is emitted by virtue of the target's temperature.

Figure 8–12 is an illustration of an elementary passive system. The basic elements of a passive system are the optical components, detector, amplifiers, and indicator. The filters are used to eliminate undesirable radiations.

The other group of systems is referred to as "active." These systems include an infra-

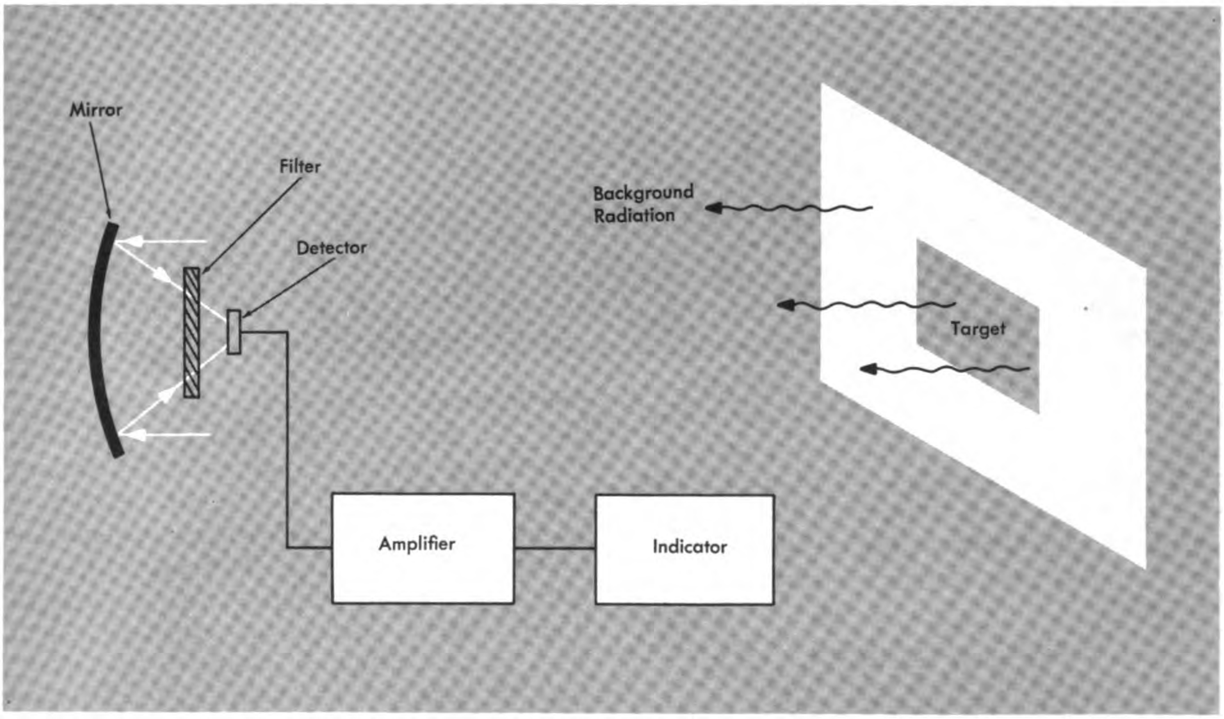

Figure 8–12. *An Elementary Passive IR System*

On the other hand, a target with a rear radiation cone of 60 degrees could not evade a missile by making a 2.5g turn. Launched astern of the target, the missile would have more than 8 seconds of guidance.

IR Tactical Devices

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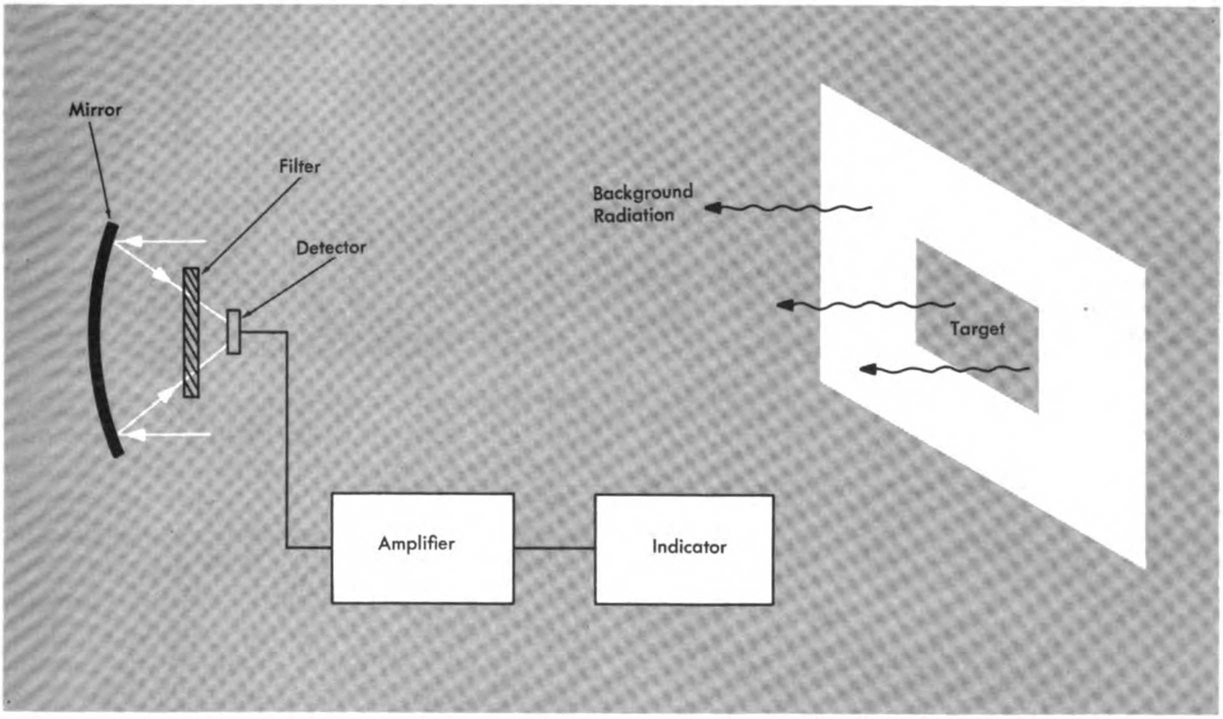

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The use of flares should be particularly effective for target aircraft whose tailpipes radiate in a narrow cone. The following factors would have to be considered in devising a flare ejection pattern:

- The missile's dynamic response.
- The precession rate of the missile's detector head.
- The target aircraft's speed and maneuverability.

Another proposed decoy method utilizes so-called "balls-of-fire." The decoy devices consist of hollow spheres of carbon heated to about 3000° K by the ignition of materials contained within them. Like the flares, these balls would be ejected in patterns rather than separately.

It has been suggested that a bomber might tow a decoy target behind it. Such a decoy could be 20 feet long and have a wing span of 16 feet. A towed decoy might be an excellent infrared countermeasure if it were small enough to be carried in the aircraft until attack was expected.

INFRARED COMMUNICATIONS

The simplest source of infrared energy is the common tungsten lamp, which is widely used in code operations by keying the lamp circuit. The principal disadvantage of this device is its inherently slow speed of response which limits Morse code operations to a speed of about eight words per minute.

A high-speed mechanical shutter will increase the speed of signaling, but other complex design problems are still being studied. These problems include resistance to shock, vibration, and weathering, and continuous operation under adverse conditions.

The rigid shock and vibration requirements have led to the development of rugged and shockproof tungsten lamps for use in all types of operations. However, the limitations in code speed remain unchanged, since the lamp filament must still be keyed. A further means of increasing the speed of operations is by reducing the actual mass of the tungsten filament. This method, in conjunction with the use of half-wave rectification, has rendered tungsten-lamp transmitters capable of achieving code speeds and modulation percentages which are within the range of most infrared receivers.

The primary requirement for infrared filters is the restriction of the visible-light radiation from the source. Filter design parameters include characteristics of the source, the human eye, and the intended receiving element.

Modulation of infrared radiation at a transmitting source is basically accomplished by one of two means: either the radiation source itself is modulated, or the outgoing beam of radiation is interrupted at a preset rate.

In the first method, electrical modulation of the current through a tungsten lamp or a gas discharge source is the commonly employed practice. For modulating the outgoing beam, electro-optical devices like the Kerr cell have recently been considered, but most military systems use mechanical modulation. This mechanical modulation is effected through the

use of vibrating mirrors and various beam-chopping devices. In RF systems, modulation is produced by causing supersonic vibration of some optical element.

The major advantage of electrical methods of modulation is their high degree of efficiency. Although mechanical methods are not quite as efficient, the equipment is generally lighter in weight. The modulation technique that is selected for a system may determine such characteristics as size, power, efficiency, and security of the source, and may largely affect the design of the receiving equipment.

Infrared receiver amplifiers are designed with primary consideration to detectors with which they will be employed. This is done to avoid restriction of the inherent sensitivity of the detector due to limitations produced by incompatible amplifier design.

One important condition is that the amplifier have a lower noise level than the detector itself. This noise problem also arises in the selection and design of all auxiliary equipment, such as the power source for the amplifier.

Another feature taken into consideration is amplifier gain. A constant gain is highly desirable, with the signal level remaining virtually unchanged during time of measurement.

Also, with an AC amplifier, the interrupting or chopping frequency should allow the longest practical interval of observation time.

The most widely used forms of amplification for the weak output signals from the infrared detectors are DC and AC amplifiers and the photomultiplier.

CLASSIFICATION OF SYSTEMS

Infrared systems are generally divided into two major classifications according to their basic operating characteristics. One of these groups is composed of passive systems which do not employ any transmission of infrared radiation. These systems operate by detecting the radiation which is emitted by virtue of the target's temperature.

Figure 8–12 is an illustration of an elementary passive system. The basic elements of a passive system are the optical components, detector, amplifiers, and indicator. The filters are used to eliminate undesirable radiations.

The other group of systems is referred to as "active." These systems include an infra-

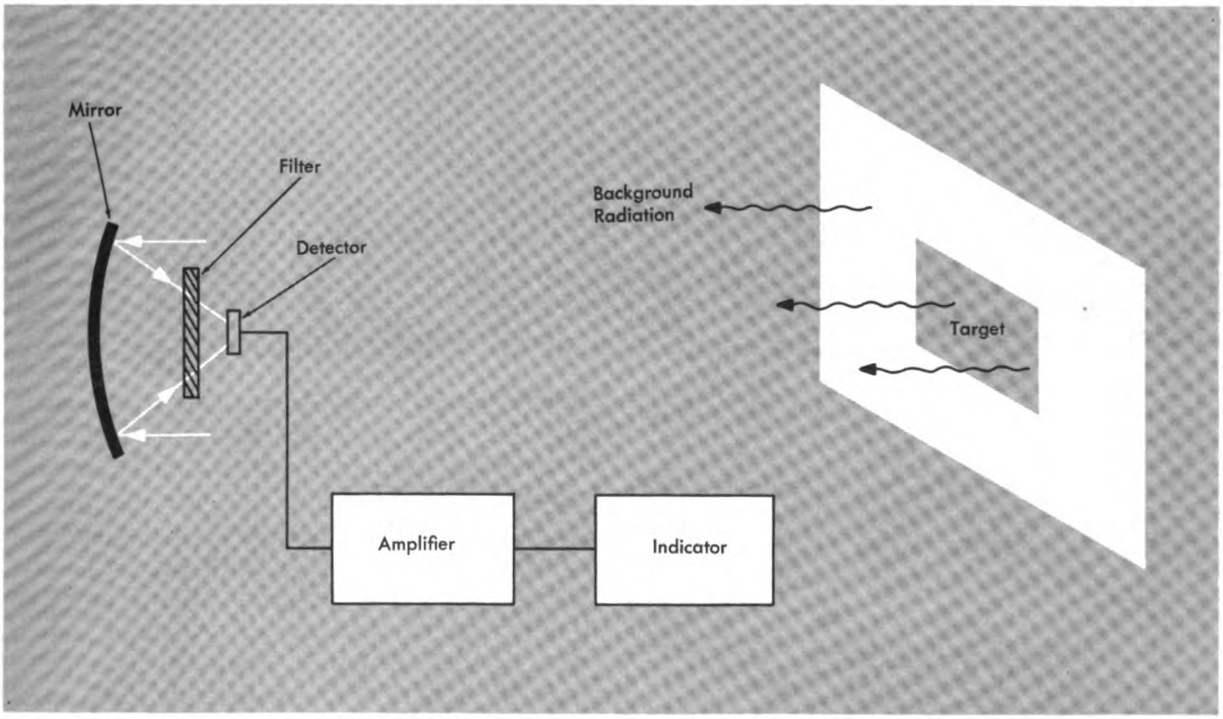

Figure 8–12. *An Elementary Passive IR System*

On the other hand, a target with a rear radiation cone of 60 degrees could not evade a missile by making a 2.5g turn. Launched astern of the target, the missile would have more than 8 seconds of guidance.

IR Tactical Devices

SMOKE. It may be possible to decrease the infrared detectability of an aircraft by creating smoke in its exhaust.

FLARES AND DECOYS. Some theoretical studies and preliminary tests have indicated that flares may decrease the vulnerability of an aircraft to infrared guided missiles. In a given situation, the flare would serve as a decoy. It would be ejected from the aircraft attempting to evade infrared detection. The probable requirements for such a flare are as follows:

- It should radiate 20,000 watts or more between 0.75 and 3.0 microns, reaching this brilliancy in about 0.25 seconds and continuing for 6 seconds or more.
- It should not produce radiation which can be seen by the naked eye beyond ½ mile.

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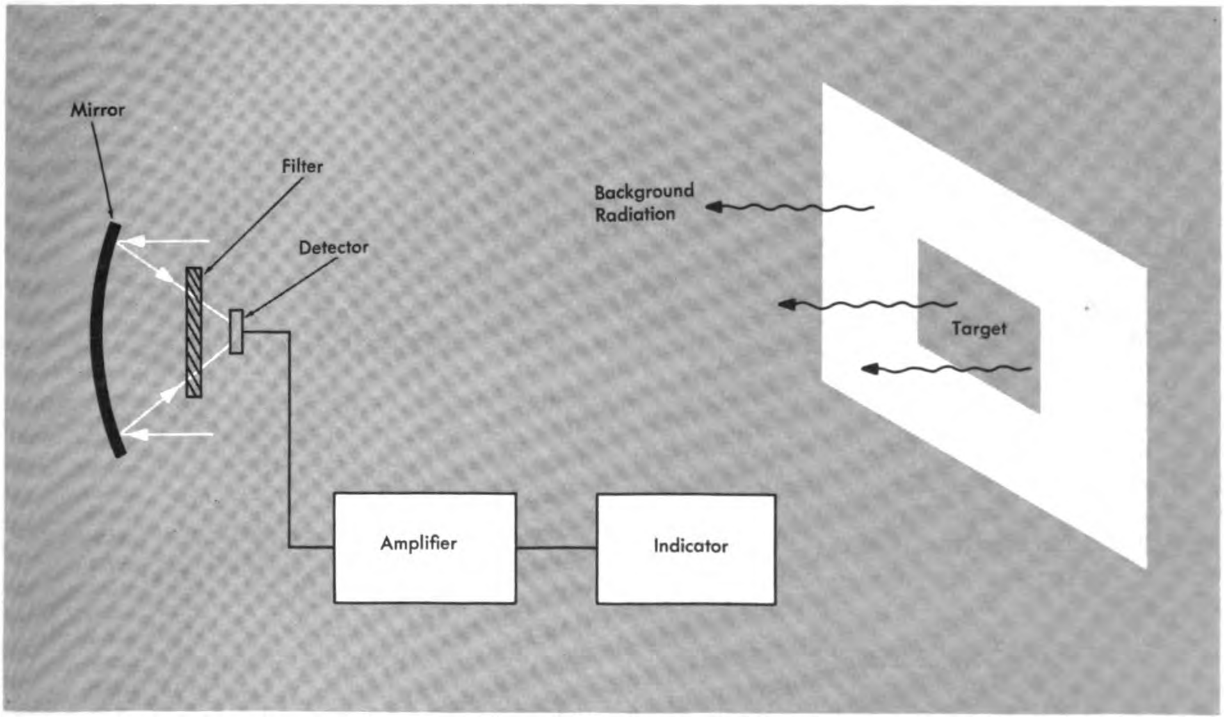


Figure 8–12. *An Elementary Passive IR System*

red radiation source which is directed toward the target. Figure 8–13 illustrates a typical active system.

In an active system, a portion of the transmitted energy is reflected by the target and returned to the detector. Image-forming detectors are generally used in active systems in order to identify the target.

Passive systems have several advantages. They provide a higher degree of security than active systems, and they are not subject to jamming. Moreover, since the intensity of the reflected radiation decreases as the square of the distance, the active system suffers a power decrease in energy level with range. For these reasons, passive systems have been much preferred for military applications.

Active and passive systems are further categorized on the basis of the tactical use for which the equipment was developed. These tactical uses include communications, beacons, reconnaissance, recognition, navigation, direction finding, tracking, homing, fire control, and bombing.

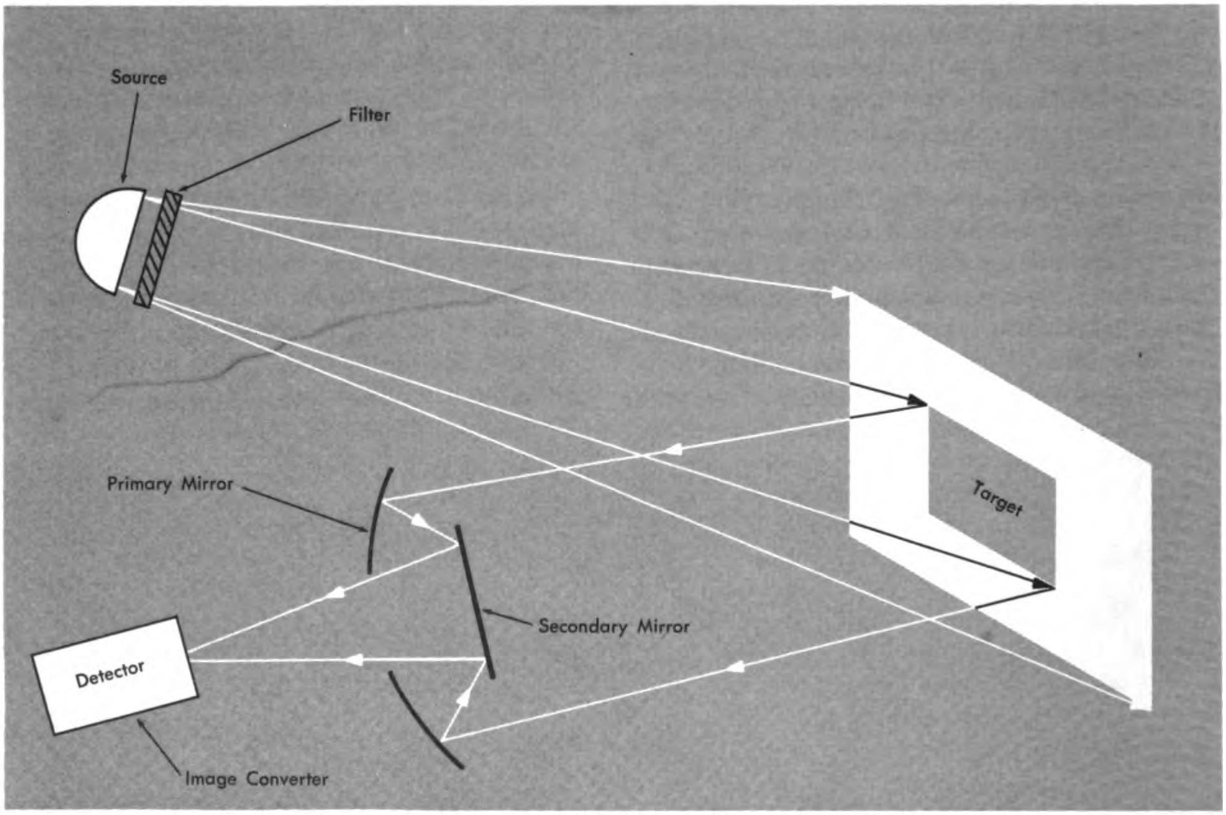


Figure 8–13. ***An Active IR System***

CHAPTER 9

Recent Developments

The capabilities of electronic devices have grown at a fantastic rate since the close of World War II. Many of these instruments have given the governments of the world far more efficient means to defend themselves.

Infrared, the increased power of the early warning radars, and the sophistication of the fire control radar have placed a heavier burden on the field of electronic warfare.

Space vehicles and the struggle between electronic countermeasures and electronic countercountermeasures have produced many new problems.

Modern space vehicles and missiles rely largely on electromagnetic energy for control and guidance. They are therefore subject to electromagnetic countermeasures. However, countermeasures have not been developed to cover the entire electromagnetic spectrum from DC through cosmic rays. With the requirement to counter these new threats, it becomes more apparent that the entire spectrum must be explored and new neutralizing countermeasures developed.

Many revolutionary items of electronic equipment are being used to meet the new threats. One of the foremost projects of interest to the EW officer is the SAMOS reconnaissance satellite. Another follow-on project for the SAMOS is the MIDAS missile detection system. The preliminary work on the major guidance and control system components from the SAMOS and MIDAS systems have been flight-tested in the series of Discoverer test satellites.

Many revolutionary items of electronic equipment are being used to meet the challenge.

TRANSISTORS

The transistor stands high on the list of valuable new developments. It passed from a laboratory curiosity to a household word overnight. It is doubtful if any product of the electronic research laboratory has ever made such an impression on layman and scientist alike. This is understandable considering the fact that the transistor has been successfully employed in practically every branch of human endeavor since it was introduced in 1948.

Of the many devices which can amplify, the transistor has been the first major discovery to offer serious competition to the vacuum tube. In military equipment the transistor is looked to for great savings in weight, space, power requirements, and reliability. Another advantage of the transistor over the vacuum tube is its ability to withstand shock.

However, where high frequencies and high power are required, vacuum tubes still offer the most practical solution. Transistors, while they operate at lower temperatures than vacuum tubes, generate more noise because they cannot be made small enough to compensate for their slow moving electrons.

PRINTED CIRCUITS

The development of printed circuit techniques in the production of electronic components is a recent important advancement. Such items as conductors, resistors, capacitors, and inductances are changed from three dimensions to two. Advantages are size, weight, time, and cost reduction, plus uniformity of production.

The process of printing circuits is basically simple. A conductor is made by depositing metallic paint in a line on an insulating surface. A resistor is formed in essentially the same manner, except that the metallic paint used has a higher resistance. An inductance is formed by depositing conducting material in a spiral. A capacitor is made by applying metallic paint to both sides of the insulating base which holds the circuitry.

The methods for coating the insulator with these chemicals include painting, spraying, electroplating, and die stamping. When conducting wires from different portions of the circuit must cross each other, undesired contact is avoided by having one of the conductors go through the base plate and continue on the other side.

MODULAR CONSTRUCTION

A module is an assembly of components to form a new and larger component which meets functional specifications. Starting from raw or semiprocessed materials, machines automatically manufacture ceramic materials and adhesive carbon resistors, print conducting circuits, and mount resistors, capacitors and other miniaturized component parts on standard uniform steatite wafers. The wafers are stacked very much like building blocks to form a module that performs all the functions of one or more electronic stages, as illustrated in figure 9–1.

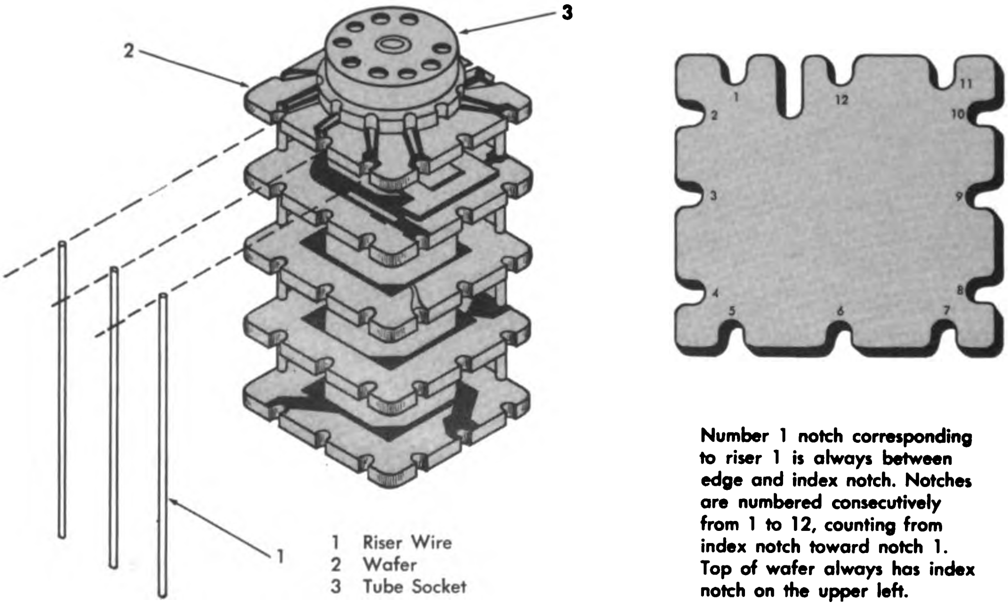
The completed module is a physically standardized, interchangeable subassembly combining all the requirements of an electronic circuit with ruggedness, reliability and extreme compactness.

The modules may be connected in a wide variety of arrangements by riser wires which serve as structural elements as well as conductors.

The module weighs very little, but is very strong and capable of withstanding heavy shock loads.

SOLID-STATE ELECTRONICS

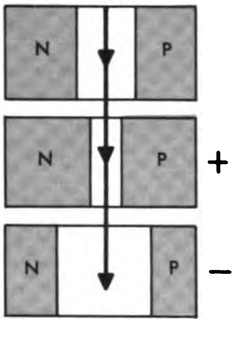
A new concept is being brought about by the demands of guided missiles and space



Number 1 notch corresponding to riser 1 is always between edge and index notch. Notches are numbered consecutively from 1 to 12, counting from index notch toward notch 1. Top of wafer always has index notch on the upper left.

Figure 9–1. *Modular Construction*

DEPLETION LAYER



With no voltage across the diode, width of depletion layer is constant (top). A forward voltage (center) narrows it; a reverse voltage (bottom) makes it wider.

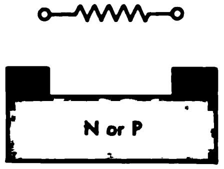
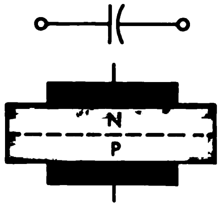
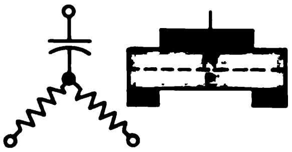
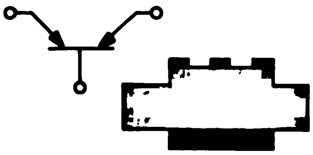
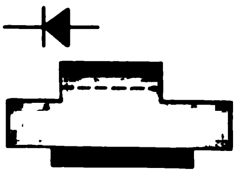
	**RESISTOR** Formed by applying ohmic or nonrectifying contacts to a semiconductor wafer.
	**CAPACITOR** Formed by utilizing the capacitance of a relatively large area of P-N junction.
	**DISTRIBUTOR CAPACITOR** Formed by combining the resistive and capacitive element.
	**TRANSISTOR** Formed by utilizing diffuse-base transistor techniques.
	**DIODE** Formed by diffused-base method.

Figure 9–2. *Solid-State Electronics*

travel. A complete microminiaturized amplifier may consist of a multistage solid-state circuit in which semiconductor materials perform a variety of component functions. The entire amplifier might be mounted in a case no larger than the tiny present-day transistors.

Different circuit functions, which can be achieved using semiconductor materials, are shown in figure 9–2. To date the equivalent of an inductor has not been found.

Using controlled masking, etching, and diffusion processes, a tiny multivibrator has been developed which measures $\frac{1}{4}$ x $\frac{1}{8}$ x $\frac{1}{32}$ inches. This circuit performs functions which would normally require two separate transistors, eight resistors, and two capacitors. A phase shift oscillator, which ordinarily would use one transistor, five resistors, and three capacitors, has been fabricated on a single crystal of the same dimensions.

There are plans to develop molecular electronic elements which perform functions of widely used conventional circuits. These include an audio amplifier, a video amplifier, and a multivibrator.

MASER

A new microwave device called the maser has been developed. The letters of this word stand for *microwave amplification by simulated emission of radiation.* The maser represents the ultimate in high-fidelity amplification.

The best previous amplifier, using vacuum tubes, produced a mixed signal which combined an amplified version of the input with a wide assortment of oscillations originating in the tubes themselves. As the input signal became weaker a point was reached where the input, though still amplified, could no longer be recognized in the output.

The great virtue of the maser is that it generates practically no noise. It can detect much weaker signals than other amplifiers, and can pick up radio waves from far more distant points in space.

The development of the maser has made it possible for a radar signal to be bounced off Venus and detected. This is quite an accomplishment, considering that Venus is a minimum of 28,000,000 miles away.

JUNCTION-DIODE AMPLIFIER

Within the past year, the junction-diode, a two-element solid-state device, has come into its own as one of the best all around amplifying devices.

Maser and junction-diode amplifiers add very little operating noise to the signals they amplify. Noise is basically caused by disorganized motion of atoms and electrons. The temperature of an object is a measure of this disordered motion of molecular particles.

The vacuum tube, which depends on heat to boil the electrons from the cathode, starts with a noise disadvantage. Transistors and junction-diodes, which operate at room temperatures, are at a disadvantage with the maser, which is cooled by liquid helium to approximately −268° C.

Even though transistors operate at lower temperatures than vacuum tubes, they generate more noise because they cannot be made small enough to compensate for their slow moving electrons.

Junction-diodes, commonly called tunnel diodes, are free of this limitation because their operation depends on charges moving back and forth in a very narrow area.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

CURTIS E LeMAY
Chief of Staff

R. J. PUGH
Colonel, USAF
Director of Administrative Services

Explanation of Terms

This is limited to those terms, nicknames, abbreviations, and definitions not contained in other Air Force publications such as AFM 11–1, *Glossary of Standardized Terms*, and AFM 100–39, *Communications-Electronics Terminology, Definitions, and Abbreviations.*

AAFCS (antiaircraft fire control system). Acquisition radars, tracking radars, and computers used to control AA weapons.

AEW (airborne early warning) radar. High-powered radar set installed on aircraft for distant detection of approaching enemy aircraft.

AI (airborne interception). Air defense function performed by an interceptor equipped with airborne radar.

aided tracking. A system for tracking a moving object in azimuth, elevation, or range (or any combination of these) by means of a semiautomatic radar tracking mechanism. (The tracking mechanism requires some manual control.)

AN nomenclature system. A joint Army-Navy-Air Force code system set up for designating certain communication and electronic equipment. The prefix AN does not imply that a particular piece of equipment is used by all the services, but merely that the designation was assigned under the AN nomenclature system.

antenna bandwidth. In electronics, the range of frequencies within which the performance of an antenna, in respect to some characteristic, conforms to a specified standard.

antenna beamwidth. The angular width of the main lobe of an antenna radiation pattern.

area air defense control center. Principal air operations installation from which all aircraft, antiaircraft artillery, ground-to-air guided missiles, and air warning functions of an active air defense area are coordinated.

beamwidth error. An error or distortion presented on a radarscope which occurs when the width of the scanning beam causes the target to appear wider than it actually is, or when it covers the two targets in a single sweep, thus making them appear as one target.

blossom. Optimum dispersal of chaff to produce the best possible echo.

broadbeam antenna. An antenna that sends out a broad search beam.

carcinatron. Broadband voltage tuned oscillator utilizing the progressive interaction of an RF field in a slow wave structure and an electron stream in a crossed magnetic field to produce RF energy.

C-band. A radio-frequency band of 3.9 to 6.2 kilomegacycles with wavelengths of 11.8 cm to 7.3 cm.

chaff bundle/sleeve. A single package containing a group of similar or various cut metallic strips used for creating radar echoes for confusion purposes.

chaff bursts. Dispensing of a number of chaff units at timed intervals.

chaff corridor. Area in which chaff has been sown, sometimes known as the infected area or lane.

chaff jamming. Reradiation of electromagnetic energy by reflection from chaff to impair the use of enemy electronic devices.

chaff rocket. Chaff-filled rocket used to dispense chaff ahead of the aircraft.

chute. Opening in the aircraft skin, with its associated duct, lip, and fairing through which chaff is dispensed.

cobs. Bell-shaped deflections produced on an oscilloscope by frequency modulated, continuous wave jamming.

command guided missile. A missile guided by a system that requires two radars, one to track the target, the other to track the missile. A computer combines the data from each radar to give the missile necessary flight direction.

communications-electronics field. Element of aerospace power concerned specifically with the collection and transmission of information. Communications-electronics provides the facilities by which the commanders, separated from the elements of their command, may exercise administrative, logistical, and tactical direction. It provides facilities to enhance or control the operational capabilities of aircraft or missiles.

controlled devices countermeasures. Controlled electronic countermeasures against guided missiles, pilotless aircraft, proximity fuses, or similar devices.

crash program. A program set up under the pressure of an urgent requirement, the emphasis being upon speed even though the effects of such speed may be harmful to other existing programs or may require extra funding.

diplexer. 1. Coupling system which allows a radar and a communications transmitter to utilize the same antenna simultaneously or alternately. 2. Coupling unit in radio which allows more than one transmitter to operate on the same antenna.

dummy load. Device in which the output power can be absorbed, used for simulating conditions of operation for test purposes. Usually a load to simulate an antenna.

ECM homing. Act of approaching an enemy source of electromagnetic radiation guided by a receiver with directional antennas.

effective confusion quantity. Number of units necessary to hide a given target in the same resolving radar cell.

emissivity. The relative power (of a surface or a material composing a surface) to emit heat by radiation.

EW officer. USAF officer who plans electronic warfare activities to include intercept, operations, and tactical use of active airborne and ground electronic countermeasures; operates electronic warfare equipment; and serves as electronic warfare staff officer.

EW reconnaissance. Air or space mission for the purpose of gathering ELINT information.

follow-on. Any object, group of objects, technique, or procedure considered to be a second or subsequent generation in the development of the object, group of objects, technique, or procedure.

glide missile. One which has for its midcourse and reentry or terminal phases a trajectory essentially flat or gliding with respect to the earth's surface. No power is required, and the actual trajectory shape is a function of entry angle to the sensible atmosphere and the aerodynamic configuration.

helix antenna. A wire antenna formed into the shape of a helix. This type of antenna may be used to transmit or receive circularly or linearly polarized waves.

homing antenna. Type of directional antenna array that is useful when it is desired to fly directly to a target.

hyperbolic guidance. The guidance or control of guided missiles in which the difference in the time delay of radio signals transmitted simultaneously from two ground stations, arriving at the missile at different time intervals, controls the missile. This system is based on the geometric theorum that one locus of all points of fixed difference in distance from two base points is a hyperbola.

image rejection. Those characteristics of a superheterodyne receiver reducing the reception of images. Image rejection requirements are termed in db of attenuation of the image frequency response. Image rejection is improved by increasing the number of tuned circuits in the preselector, higher intermediate frequencies, narrower i-f bandwidths, and shielding.

integration. The process by which small bits of information, represented by a variable, are summed with respect to time or another variable.

IRAN (inspection and repair as necessary). A term used to identify the maintenance work under which depot-level activities inspect and repair as necessary, as contrasted with complete disassembly and overhaul.

IR dome. Dome, constructed of material that is transparent to infrared radiation, used to protect the IR equipment.

jam. To make transmissions of a radio unintelligible; to make a radio or radar set ineffective, either by the use of countertransmissions or by the use of a confusion reflector.

K. 1. Knot or knots. 2. Kelvin scale.

K-band. Frequency range which extends from approximately 10.9 to 36 kmc.

L-band. A radio-frequency band of 390 to 1550 megacycles with corresponding wavelengths of 77 to 19.35 cm.

lock-on range. The range from a radar to its target at lock-on.

Luneberg lens. An efficient electromagnetic energy reflector.

magnetic wire. Wire capable of storing information by undergoing changes in magnetization conforming to the applied current representing the desired information.

NAA. *National Aeronautic Association.*

NAVCOM (navigation countermeasures and deception). All electronics countermeasures against navigational aids.

notch antenna. An antenna in which the pattern is formed by a notch or slot in a radiating surface. Characteristics are similar to a properly proportioned conventional antenna and may be evaluated with similar techniques.

NR (noise ratio). The ratio of the noise power available at the output of a transducer divided by the noise power at the input.

ORI. *Operational readiness inspection.*

panoramic presentation. Presentation of signals as vertical deflections or intensity pips along a line with the horizontal position representing frequency.

passive navigational countermeasures. Deliberate control of transmissions from equipment capable of electromagnetic radiation to prevent enemy exploitation of such transmissions for navigational purposes. It includes radio silence, spoiling, and masking. Called CONELRAD in U.S.

P-band. A radio frequency band of 225 to 390 mc with wavelengths of 133 to 77 cm.

playback. Playing back of a recording for the purpose of reconstructing the original electrical signals as faithfully as possible.

prime contractor. A contractor having a contract directly with the government or other funding agency.

pulse doppler. 1. Radar system for distinguishing between fixed and moving targets by detecting the phase difference between the echo and coherent CW oscillator locked in phase with transmitted pulse. 2. Uses Doppler beats between the moving target and clutter at the same range to give MTI by aural indication of target in range gate.

Q. Symbol used to indicate the electrical quality or figure of merit of efficiency of a coil or circuit. Rating determined by the ratio of reactance to resistance. The higher the Q the greater the selectivity of the circuit.

QB–17. A surplus B–17 bomber converted for remote control. Target drone used to test the Nike and the Falcon.

Q factor. Rating applied to coils and resonant circuits, equal to reactance divided by resistance. Often called *Q*.

QRC offices. Offices established at Hq USAF, Hq AFLC, and Hq AFSC to approve, budget, administer, and provide active surveillance of the QRC program as affects assigned responsibilities. The Hq USAF QRC Office exercises approval authority for all QRC equipments, modifications, or installations.

radar fence. A network of radar warning stations surrounding a protected area.

radar homing. A method of missile guidance wherein a missile-borne radar provides the required intelligence.

radar illumination. 1. The use of radar to illuminate a target. 2. A method of missile guidance wherein a radar external to the missile but aimed at the target causes the target to emit echoes suitable for homing.

radar lock-on. That condition of radar operation wherein it becomes possible to track a target by automatic rather than manual means. Sometimes referred to as autotrack.

radar nautical mile. Time interval, approximately 12.361 microseconds, required for radio energy to travel 1 nautical mile and return; a total of 2 nautical miles.

radar prediction. A graphic representation of what may be expected to show on a radar screen when an actual radar scan is made; used to increase ease of recognition.

RADC (Rome Air Development Center). Responsible for research and development of ground-based electronic equipment, and tests under operational conditions. A part of Air Force Systems Command (AFSC), RADC is located at Griffis AFB, Rome, N.Y.

radio fuze. A fuze activated by a radio device; a radio proximity fuze.

raven (radar viewing navigator). Code name for electronic warfare officer.

receiver sensitivity. The lower limit of useful signal input to the receiver; limited by the signal-to-noise ratio in high gain receivers.

reflecting target. In a radar, a target that reflects radar waves.

return. In radar, an echo appearing on a radar screen.

rockoon. Rocket fired into space from a balloon at high altitudes.

roll. Strip of aluminum foil wound around a core. A number of rolls, packed in a container, form part of a unit of chaff.

ruggedizing. A technique used to improve the ability of a device or equipment to withstand a severe environment.

SAC-MIKE (SAC Missiles). Strategic Air Command Ballistic Missile Staff, Ballistic Missile Division, Inglewood, California.

scan. 1. To cause a prescribed region to be traversed by a directed beam. 2. To produce signals on a CRT indicator.

scimitar antenna. Broadband EW antenna having a curved blade radiator resembling a simitar sword.

screening. Dispensing of chaff dipoles in large volumes in order to conceal the presence of the following aircraft.

security clearance. A clearance given to a person permitting him access to classified material, equipment, or information up to and including a given classification, provided he can establish a need-to-know.

single sideband communications. A method of AM radio communications that increases transmission distance by concentrating power into one sideband.

SM. *Strategic missile.*

spoking. In electronics, a malfunction or jammed condition on a radar set in which luminous spots continue on the screen for an abnormal length of time, interfering with the presentation.

spot-size error. An error in the presentation of a radarscope, or in the interpretation of such a presentation; it is caused by the abnormally large size of the spot or blip, in which two or more objects appear as one, or in which range or azimuth presentation is distorted.

SSC (SAGE sector commander). Air Force officer responsible for the air defense of a sector.

SSPO (Strategic Systems Program Office). A central point for management control of one or more weapon system programs. The office is used at Wright Air Development Center to achieve proper phasing of actions in development, procurement, maintenance, and supply, thereby insuring timely delivery and support of weapon systems. An important function of this office is that of providing a central contact point for industry and Air Force relations.

stub antenna. Large diameter quarter wave radiator.

tactical air intelligence. Intelligence that bears upon the capabilities, limitations, vulnerabilities, and probable intentions of a hostile air force; that is, any air force that might challenge control of the air or provide support for hostile surface forces.

tactical doctrine. Standardized employment of weapons based on prior experience; doctrine is normally prescribed for field forces in suitable publications.

taped units. Chaff units taped together to form a belt for feeding to certain types of dispensers.

target cross-section. The characteristic reflective area of a target which, when placed perpendicular to the direction of the incident radar energy, is capable of intercepting just enough energy so that if this energy could be fed into a perfectly matched isotropic antenna, radiation back toward the radar receiver would duplicate that actually obtained from the target.

target discrimination. The quality of a guidance system which enables it to distinguish a target from its background or between two or more targets in close proximity.

target elevation. In radar, the angular altitude of a radar target.

target fade. A decrease or loss of signal due to interference or other phenomena.

Taunus. An antijamming device that differentiates the blip of a genuine target from that of chaff.

technological warfare. Warfare in which each contesting side strives to achieve an advantage by developments in technology.

telemetry frequencies. 216 to 225 mc available on a noninterference basis; 225 to 260 mc available for use until 1 January 1970, for missile and upper-air research; 2200 to 2300 mc probably available for missiles.

TIRBS. *Tactical radar-infrared bombing subsystems.*

track-command guidance. A method of missile guidance wherein both target and missile are tracked by separate radars. Corrective commands are sent to the missile via the coded beam. The two beams are programmed in coincidence on the target.

tracking radar (TR). A high-powered radar designed for tracking targets usually in two axes (azimuth and elevation) and equipped with pickoffs to permit accurate readout of antenna position. Range and range rate are obtained by measuring the time required for a pulse to be transmitted and received.

turbofan. A kind of turbojet engine in which a propeller or fan forces low-pressure air through ducts directly into the hot turbine exhaust at the turbine exhaust pressure.

turboprop. A gas-turbine engine designed to drive a propeller for use at intermediate aircraft speeds. Also termed propeller-turbine engine; prop jet.

TWT jammer. Broadband EW transmitter using a traveling wave tube.

UAL (unit authorization list). Electrical accounting machine list of specified equipment authorized each unit. A list that formerly authorized unit support equipment only.

UE. *Unit equipment.*

UEE. *Unit essential equipment.*

UFO. *Unidentified flying object.*

ultrasonic trainer. A ground trainer for using radar equipment in which ultrasonic waves are directed against a relief map to simulate responses occurring in actual radar operation during flight.

UR (unsatisfactory report). An Air Force report used to report a field failure or malfunction.

V-band. Radio frequency band of 46,000 to 56,000 mc.

vendor. In supply usage, any contractor, manufacturer, jobber, or commercial agency that sells something to an armed service.

very-long range. Classification of ground radar sets by slant range. Applied to equipment with a maximum range exceeding 250 miles.

very-short range. Classification of ground radar sets by slant range. Applied to equipment with a maximum range of less than 25 miles.

VHF/UHF direction finder. A ground-based direction finder capable of use along or in conjunction with surveillance radar.

WAC-Corporal. Research rocket. An early research vehicle used for experiments (before the firing of the first captured German V–2). It was replaced by the AEROBEE.

WADC (Wright Air Development Center). Air development center at Wright-Patterson AFB, Ohio.

weapon system specification. Specifications developed in accordance with military requirements, which outline the design criteria and performance requirements for a weapon, the support equipment, facilities, and manpower.

white noise. 1. Random noise, such as shot noise and thermal noise, which has a constant energy per unit bandwidth that is independent of the central frequency of the band. The name is drawn from the analogous definition of white light. 2. The electrical disturbance caused by the random movement of free electrons in a conductor or semiconductor. Since the electrical energy in this type of noise is evenly distributed throughout the entire frequency spectrum, it lends itself to electronic warfare.

X-band. A radio frequency band of 5200 to 11,000 mc with wavelengths of 5.77 to 2.73 cm respectively.

XMTR. *Transmitter.*

XMIT. *Transmit.*

References

Air Force Publications

Identification	*Title and Purpose*
AFM 11-1	**Glossary of Standardized Terms** (This manual contains standardized terms and definitions. It prescribes Air Force policy on terminology standardization and explains how terms are submitted and processed for standardization.)
AFM 36-1	**Officer's Classification Manual**
AFM 52-8	**Radar Circuit Analysis** (This manual discusses in detail the fundamentals and applications of electronics. Two-volume revision scheduled for 1962 to be titled *Electronic Circuit Analysis.*)
AFM 52-19	**Antenna Systems** (This manual discusses basic antenna and transmission line theory, typical antenna systems, practical construction practices, antenna measurements, and test equipment.)
AFM 52-31	**Guided Missiles** (This manual discusses various aspects of missiles in which the EW officer is particularly interested, such as components of guided missile control systems, sensor units for control systems, and trajectory considerations of guided missiles.)
AFM 100-11	**Basic Concepts, Missions, and Functions with C-E Applications** (This manual provides a comprehensive background regarding worldwide military and civil activities having a direct bearing on USAF C-E. It covers basic concepts and doctrines upon which present C-E concepts and doctrines are based. It presents the broad aspects of international, national, combined, joint, and USAF C-E activities. The specific functions of the individual C-E officer at all levels are outlined.)
AFM 100-12	**C-E Publications and Training** (This publication lists manuals, periodicals, books, technical orders, etc., used by C-E personnel. Information includes instructions on general content and applicability as well as how to obtain the publications. Numerous indexes and lists of publications, subjectively grouped, are included. It contains the directive for establishment and lists the minimum content of the C-E reference file. The training section is a consolidation of information regarding C-E training courses for officers and airmen. The philosophy of C-E training is also discussed.)
AFM 100-13	**C-E Policy** (This manual lists the national, combined, joint, and Air Force policies pertaining to C-E All C-E officers concerned with C-E plans and operations and with planning for C-E type facilities and systems require this manual.)
AFM 100-17	**Planning and Preparation of C-E Plans** (This manual contains information relative to C-E planning and preparation of these plans. It covers all aspects of Air Force C-E planning on a national and international scale. It prescribes and illustrates methods of preparing plans with definite formats illustrating the acceptable types of C-E plans. In addition to the general matters relative to C-E plans, this manual describes the methods of operation of the various staff agencies and special combined C-E problems and working principles concerning these specific staff agencies.

Identification	*Title and Purpose*
AFM 100–28	**Ground Radar Evaluation** (This manual presents radar evaluation procedures that will produce statistically reliable measures of radar station detection and tracking performance. It also describes the detecting probability theory, methods of radar evaluation, and the use of evaluation data.)
AFM 100–29	**Electromagnetic Wave Propagation Planning** (This manual discusses the phenomena of electromagnetic wave propagation. The basic laws and theory of such propagation are briefly and simply discussed. Information of value concerning electromagnetic wave propagation is included. Characteristics of propagation from the VLF band through the SHF band are presented.)
AFM 100–35	**Mutual Electromagnetic Interference** (This manual provides information concerning the causes of interference in communication-electronics equipment and outlines some procedures and techniques by which interference can be identified and analyzed, and it's sources located, eliminated, or suppressed.)
AFM 100–38	**C-E Charts, Symbols, Formulas, and Tables** (This manual contains a brief description of the characteristics of large-scale topographic charts of interest to the staff officer. A resume of the telecommunication maps and charts of foreign countries is provided. Symbols used by the military forces, domestic and foreign, are included. It also contains a concise reference source of formulas, tables, and useful data frequently used.)
AFM 100–39	**Communications-Electronics Terminology, Definitions, and Abbreviations** (This publication contains a listing of nicknames, abbreviations, acronyms, and terms used with C-E systems equipment and activities.)
AFM 100–43	**Electronic Warfare** (This publication covers that information which a C-E staff officer would require on the subject of electronic warfare.)

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